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Hedonic and Nonhedonic Differential Outcome Effects in Acquisition, Retention, and Transfer of Delayed Matching-to-Sample Performance in Pigeons

by

Ronald Kelly ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Hedonic and Nonhedonic Differential Outcome Effects in Acquisition, Retention, and Transfer of Delayed Matching-to-Sample Performance in Pigeons* submitted by *Ronald Kelly* in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*

Douglas S. Grant, Ph. D.
Supervisor

Marcia L. Spetch, Ph. D.

C. Donald Heth, Ph. D.

Norman R. Brown, Ph. D.

W. David Pearce, Ph. D.

William A. Roberts, Ph. D.
Exernal Reader

July 16, 1999

Abstract

In certain stimulus situations, whenever an animal performs particular instrumental responses, it receives unique reinforcing outcomes. For example, in the presence of a certain shrub stimulus (S1), a particular "reaching-up" instrumental response (R1) may result in a unique reinforcing berry outcome (O1), whereas in the presence of a certain grass stimulus (S2), a particular "reaching-down" instrumental response (R2) may result in a unique reinforcing seed outcome (O2). In short, over the many situations an animal encounters, distinctive stimulus-response sequences are bound to result in unique reinforcing outcomes (e.g., S1-R1→O1, and S2-R2→O2). As a result, the animal may come to *expect* a unique reinforcing outcome whenever a certain stimulus situation is encountered (e.g., O1 is *expected* whenever S1 occurs, and O2 is *expected* whenever S2 occurs). Moreover, this expectancy may, in some way, enhance or facilitate appropriate instrumental responding (e.g., whenever O1 is expected, R1 is more likely, and whenever O2 is expected, R2 is more likely).

Differential outcome effects (DOEs) with pigeons pertain to particular enhancements of delayed matching-to-sample (DMTS) performance (e.g., stronger acquisition, retention, and transfer) if each correct stimulus-response sequence in the task is always followed by a specific reinforcing outcome (i.e., S1-R1→O1, and S2-R2→O2), compared to if each correct sequence is followed equally often by both outcomes (i.e., S1-R1→O1 *or* O2, and S2-R2→O1 *or* O2). Experiment 1 compared DOEs using "hedonic" outcomes (i.e., food and no food) to DOEs using "nonhedonic" outcomes (i.e., red and green). Experiment 2 sought to enhance nonhedonic DOEs by using "multidimensionally-different" nonhedonic outcomes (i.e., red and no red) and by

instituting additional procedural modifications. Experiment 3 was intended to reevaluate nonhedonic DOEs with "unidimensionally-different" nonhedonic outcomes (i.e., red and green) using those additional procedural modifications. Experiment 3 also tested a "secondary-reinforcement" account of nonhedonic DOEs with red and no-red outcomes. In general, results provided considerable evidence of a role for central expectancies, independent of any role for behavioral mediation, in nonhedonic DOEs with pigeons in DMTS tasks.

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List of Abbreviations (in alphabetical order)

ANOVA	analysis of variance
CDO	color differential outcomes
DMTS	delayed matching-to-sample
DO	differential outcomes
DOE	differential outcome effect
HDO	hedonic differential outcomes
ITI	intertrial interval
MDO	multidimensional differential outcomes
NDO	nondifferential outcomes
O	outcome
ODR	outcome discrimination ratio
R	response
S	stimulus
SDR	sample discrimination ratio
UDO	unidimensional differential outcomes

Introduction

On trials in a conditional discrimination, if one stimulus (S1) had been presented, then one response choice (R1) is correct and results in a reinforcing outcome whereas a second response choice (R2) is incorrect and results in nonreinforcement. Alternatively, if a second stimulus (S2) had been presented, then R2 is correct and R1 is incorrect. For example, on trials beginning with presentation of a green light, choice of a horizontal line orientation is correct and choice of a vertical line orientation is incorrect. Alternatively, on trials beginning with a red light, choice of vertical is correct and choice of horizontal is incorrect. In short, on any given trial in a conditional discrimination, correct and incorrect response choices are conditional upon which stimulus had been presented on that trial.

The *differential outcome effect* (DOE) refers to enhanced conditional discrimination performance in a *differential outcome* (DO) condition, in which a correct S1-R1 sequence always results in one kind of reinforcing outcome (O1; e.g., food) and a correct S2-R2 sequence always results in a second kind of reinforcing outcome (O2; e.g., water). By comparison, weaker performance is typically observed in a *nondifferential outcome* (NDO) condition, in which both of the two correct sequences, S1-R1 and S2-R2, are as likely to result in O1 as to result in O2 (see Table 1) (Trapold, 1970; Trapold & Overmier, 1972; for a recent review, see Goeters, Blakely, & Poling, 1992). The DOE is a robust phenomenon that has been observed in a number of species, including rats (e.g., Carlson, 1974; Carlson & Wielkiewicz, 1972, 1976), chickens (Poling, Temple, & Foster, 1996), dogs (Overmier, Bull, & Trapold, 1971), humans (e.g., Dube, Frederick, & McIlvane, 1989; Maki, Overmier, Delos, & Gutmann, 1995), and pigeons (e.g., Peterson,

1984; Peterson & Trapold, 1980; DeLong & Wasserman, 1981; Edwards, Jagielo, Zentall, & Hogan, 1982; Jones & White, 1994; Santi, 1989; Santi, Ducharme, & Bridson, 1992).

The DOE has frequently been examined in the delayed matching-to-sample (DMTS) task with pigeons, an instantiation of the conditional discrimination in 3-key pecking chambers (e.g., Alling, Nickel, & Poling, 1991a, 1991b; Brodigan & Peterson, 1976; Ducharme & Santi, 1992; Peterson, Wheeler, & Armstrong, 1978; Peterson, Wheeler, & Trapold, 1978; Edwards et al., 1982; Peterson & Trapold, 1982; Urcuioli, 1990, 1991; Zentall & Sherburne, 1994). In this preparation, a "sample" stimulus, either S1 or S2, is presented on the center key at the beginning of each trial. Next, following a brief delay (e.g., 0 s), two test stimuli are presented, one on the left key and the other on the right, and R1 or R2 is given by the subject pecking one of the two test stimuli. Following a correct response choice, O1 or O2 is presented via an illuminated magazine opening beneath the row of three keys, and an ensuing intertrial interval (ITI; e.g., 15 s) precedes the next trial. Following an incorrect response choice, the trial terminates immediately (i.e., neither O1 nor O2 occur), and an ensuing ITI precedes a repeat of that trial until a correct response choice is given (i.e., a correction procedure).

In a DO condition, for example, if a green sample had been presented on the center key, then a peck response to a horizontal line orientation test stimulus, whether it appears on the left- or on the right-side key, is correct and results in a brief (e.g., 3 s) presentation of an accessible food hopper ("food") in the illuminated magazine opening, followed by the ITI; alternatively, a peck response to a vertical line orientation test stimulus, which appears on the remaining side key, is incorrect and immediately

terminates the trial, and the ensuing ITI concludes in a correction trial. Additionally, if a red sample had been presented on the center key, then a peck response to the vertical test stimulus, whether it appears on the left- or on the right-side key, is correct and results in a brief presentation of an inaccessible food hopper ("no food") in the illuminated magazine opening, followed by the ITI; alternatively, a peck response to the horizontal test stimulus, which appears on the remaining side key, is incorrect and immediately terminates the trial, and the ensuing ITI concludes in a correction trial.

In an NDO condition, by comparison, both of the two correct sample-response sequences (i.e., green-horizontal, red-vertical) are as likely to result in the food outcome as to result in the no-food outcome. Thus, the DOE in the DMTS task with pigeons manifests as stronger performance in the DO condition, compared to performance in the NDO condition (e.g., Brodigan & Peterson, 1976; Edwards, et al., 1982; Peterson & Trapold, 1982; Peterson et al., 1978; Urcuioli, 1990).

In a typical experiment, stronger performance in the DO condition can be revealed in at least three different indicants: (1) faster and stronger acquisition, (2) stronger retention under conditions of extended delays, and (3) transfer to a novel procedure. On the first indicant, rate of acquisition of accurate matching is usually faster, and asymptotic level of accuracy is often higher, in the DO condition than in the NDO condition (e.g., Brodigan & Peterson, 1976; Urcuioli, 1990). This difference is typically attributed to faster and stronger learning (i.e., establishment of reference memories; see e.g., Honig & Thompson, 1982; Wasserman, 1986) of the associations between the samples and the correct test stimulus responses in the DO condition than in the NDO condition. On the second indicant, on trials in which an extended delay is interpolated

between offset of the sample and onset of the test stimuli, the rate of decline in accurate performance is usually slower in the DO condition than in the NDO condition (e.g., Honig, Matheson, & Dodd, 1984; Peterson et al., 1978; Urcuioli, 1990). This difference is typically attributed to stronger and more durable working memory (e.g., Honig, 1978) of sample information on trials in the DO condition than in the NDO condition. On the third indicant, when associates of the food and no-food outcomes, or the outcomes themselves, are followed by the opportunity for test stimulus responding in a novel matching procedure, transfer of matching performance is usually present in the DO condition and absent in the NDO condition. This difference is typically attributed to the availability of mediators of performance in the DO condition, but not in the NDO condition (e.g., Peterson & Trapold, 1980; Urcuioli, 1990; Zentall, Sherburne, & Steirn, 1992).

Expectancy theory provides one possible account of DOEs (Trapold & Overmier, 1972). Accordingly, a DO condition ensures that each of the two correct sample-response sequences always results in a unique outcome: that is, a correct S1-R1 sequence always results in O1, and a correct S2-R2 sequence always results in O2. As training proceeds, this correlation between correct sequence and outcome supports the establishment of *differential outcome expectancies* to presentations of S1 and S2. In short, presentation of S1 comes to reliably activate a unique expectancy of O1, and presentation of S2 comes to reliably activate a unique expectancy of O2. An expectancy of a forthcoming event of biological relevance, such as food or no food, is believed to consist of a distinct, discriminable, and memorable central representation (e.g., Roitblat, 1982) of that event. Thus, salient differential outcome expectancies provide a

discriminative basis for correct test stimulus choice, in addition to that provided by the sensory features of S1 and S2. Specifically, the expectancy of O1 (in addition to the sensory features of S1) controls choice of R1, and the expectancy of O2 (in addition to the sensory features of S2) controls choice of R2. This additional basis for accurate DMTS performance facilitates learning and working memory in the conditional discrimination, and provides mediators for transfer to a novel matching procedure.

In contrast, after training in an NDO condition, in which there is zero correlation between correct sample-response sequence and outcome, the same expectancy becomes established to presentations of S1 and S2. Thus, with food and no-food outcomes, presentation of S1 activates an expectancy of food/no food, and presentation of S2 also activates the same food/no-food expectancy. Note that such *nondifferential outcome expectancies* cannot provide a discriminative basis to correctly choose R1 and R2 over trials in the conditional discrimination. Therefore, subjects must rely only upon the sensory features of S1 and S2 to provide the basis for learning and working memory performance. In addition, nondifferential outcome expectancies cannot provide mediators for transfer to a novel matching procedure. To summarize then, the availability of differential outcome expectancies in the DO condition and the unavailability of such expectancies in the NDO condition provides, on expectancy theory, a central (cognitive) mechanism for DOEs.

By comparison, *behavioral-mediation theory* rejects postulation of such hypothetical constructs as expectancies (e.g., Alling et al., 1991a, 1991b; Goeters et al., 1992). Instead, this theory explains DOEs more simply in terms of the discriminative function of explicit behavioral patterns which come to be elicited by stimuli that are

associated with important biological events. Accordingly, due to the correlation between correct sample-response sequence and outcome in the DO condition, presentation of S1 comes to reliably activate a unique response pattern that is appropriate to reception of O1 (e.g., pecking S1, if O1 is food), and presentation of S2 comes to reliably activate a unique response pattern that is appropriate to reception of O2 (e.g., not pecking S2, if O2 is no food). On behavioral-mediation theory, there are distinct, discriminable, and memorable proprioceptive stimuli that arise from each of these two patterns of responding. These stimuli provide a discriminative basis for correct test stimulus responding in addition to the sensory features of S1 and S2. Specifically, one pattern of responding results in proprioceptive stimuli that (combined with the sensory features of S1) control choice of R1, and a second pattern of responding results in proprioceptive stimuli that (combined with the sensory features of S2) control choice of R2. This additional basis for accurate DMTS performance facilitates learning, working memory, and transfer performance in the DO condition.

By contrast in the NDO condition, due to the zero correlation between correct sequence and outcome, the same pattern of responding would be activated by presentation of both S1 and S2. Consequently, the same proprioceptive stimuli would arise from the responses activated by both S1 and S2. Therefore, subjects must rely only upon the sensory features of S1 and S2 to provide the basis for learning and working memory performance. In addition, nondifferential proprioceptive stimuli cannot mediate transfer in a novel matching procedure. To summarize then, the availability of differential proprioceptive stimuli that arise from sample-activated response patterns in the DO condition, and the unavailability of such differential proprioceptive stimuli in the

NDO condition provides, on behavioral-mediation theory, a much simpler peripheral (i.e., behavioral) mechanism for the DOE (see also, e.g., Cohen, Brady, & Lowry, 1981; Eckerman, 1970; Urcuioli, 1985; Urcuioli & DeMarse, 1994; Urcuioli & Honig, 1980; Zentall, Hogan, Howard, & Moore, 1978).

In many DOE experiments, behavioral-mediation theory and expectancy theory make the same prediction, viz., stronger performance in the DO condition than in the NDO condition. Therefore, a parsimony criterion frequently favors the simpler behavioral-mediation explanation of observed DOEs over the more complex expectancy account. In this regard, it is notable that many DOE experiments have typically used as outcomes, events that represent nearly opposing extremes along an affective or hedonic continuum (e.g., food and no food). Marked difference in hedonic value of the outcomes may provide the basis for the frequently observed differences in response patterns (e.g., pecking and not pecking) that come to be activated by presentations of S1 and S2 in the DO condition. In other words, differential proprioceptive stimuli may be a direct consequence of the difference in hedonic values of the two outcomes.

With pigeons, presentation of the "favorable" sample, associated with an hedonically positive outcome (i.e., food), typically elicits a keypecking response pattern (Brown & Jenkins, 1968), whereas presentation of the "unfavorable" sample, associated with an hedonically negative outcome (i.e., no food), typically elicits a withdrawal response pattern (Wasserman, Franklin, & Hearst, 1974). Differences in response patterns activated by presentations of S1 and S2 may provide differential proprioceptive stimuli in the DO condition. By contrast in the NDO condition, presentation of S1 and S2, each associated with both food and no food, should become hedonically equivalent.

Hence, both samples should activate the same response pattern and, consequently, should fail to provide differential proprioceptive stimuli. On this account, "hedonic" DOEs in experiments that have used food and no food outcomes can often be best explained by simple peripheral mediation (i.e., behavioral-mediation theory), and an appeal to a more complex central process (i.e., expectancy theory) is often unnecessary (but see, e.g., Sherburne & Zentall, 1995b).

Therefore, to disentangle the predictions of behavioral-mediation theory and expectancy theory, and thereby provide a more convincing demonstration of a role for expectancies in DOEs, the experimenter must ensure that differential response patterns that may be activated by samples in the DO condition do not differ from those activated by samples in the NDO condition. If this requirement is met, then differential proprioceptive stimuli should be no more available in the DO condition than in the NDO condition. Hence, any enhancement of DMTS performance in the DO condition would strongly implicate a role for central expectancies in hedonic DOEs, independent of the role for peripheral responses.

How might an investigator ensure that differential sample responding is equated in the DO and NDO conditions? In some DOE experiments with food and no-food outcomes, during baseline training in the DO condition, subjects periodically receive Pavlovian conditioning trials in which the unfavorable sample is paired with the hedonically positive outcome (e.g., DeLong & Wasserman, 1981; Urcuioli, 1990). Other experiments have used outcomes which presumably have similar hedonic values, but differ primarily in terms of motivational systems, such as food and water (e.g., Brodigan & Peterson, 1976; Honig et al., 1984; Peterson, 1984). And still other experiments have

used outcomes which differ less markedly along the hedonic continuum, such as different nonzero probabilities (e.g., 1.0 and 0.2) of food (e.g., DeLong & Wasserman, 1981; Santi & Roberts, 1985), and different types of food, such as corn and peas (Edwards, et al., 1982). Basically, each of these procedures is designed to equate the response patterns (i.e., activate keypecking) to presentations of both S1 and S2 and, hence, to reduce or eliminate unique proprioceptive stimuli that may result from differential sample responding in the DO condition. Thus, hedonic DOEs in such experiments are less amenable to a simple behavioral-mediation explanation, and seemingly require the more complex expectancy account.

Still, it is reasonable to argue that even these "nondifferential sample responding" control procedures do not completely rule out a possible behavioral-mediation account. In these procedures, activation of different response patterns may still occur to presentation of S1 and S2 and, as a consequence, differential proprioceptive stimuli may still be available to facilitate performance in the DO condition. To illustrate with food and water outcomes, presentation of the food-associated sample may come to activate one distinctive, "food-related", pattern of pecking (e.g., sharp, closed-beaked, "eating-like" pecks) whereas presentation of the water-associated sample may come to activate a second distinctive, "water-related", pattern of pecking (e.g., soft, open-beaked, "drinking-like" pecks) (Jenkins & Moore, 1973). The differential proprioceptive stimuli that would result from these distinct patterns of pecking could provide the discriminative basis for stronger performance in the DO condition. In similar manner with differential outcomes from the same motivational system (e.g., 1.0 and 0.2 probabilities of food, or corn and peas), the favorable sample (i.e., the sample associated with a 1.0 probability of food, or,

say, very appetizing corn) may activate vigorous keypecking whereas the "less favorable" sample (i.e., the sample associated with a 0.2 probability of food, or less appetizing peas) may activate less vigorous keypecking. In short, evidence of DOEs with control procedures that use two hedonically positive outcomes (and, at least with dogs, two hedonically negative outcomes; see Overmier et al., 1971), although suggestive of a role for central expectancies, does not completely rule out the possibility that hedonic DOEs were mediated by unique proprioceptive stimuli that resulted from differential sample-activated behaviors.

An alternate version of the nondifferential sample-responding control procedure involves use of two outcomes that carry little or no biological or hedonic relevance to the subject (Trapold & Overmier, 1972, p. 450). From a methodological standpoint, such "nonhedonic" differential outcomes[1] should be unlikely to generate systematically different patterns of sample responding. Consequently, nonhedonic outcomes should not eventuate in discriminative proprioceptive stimuli that could facilitate performance in the DO condition, any more than such stimuli might be available to facilitate performance in the NDO condition. Thus, any enhancement of conditional discrimination performance in a DO condition with nonhedonic outcomes would provide converging evidence for the importance of central expectancies, independent of the role of behavioral mediation, in DOEs.

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[1] The term "nonhedonic differential outcomes" is not meant to imply that the two outcomes have no biological relevance whatsoever. It simply means that, *a priori*, the outcomes should not systematically *differ* in hedonic value, in contrast to the way in which, for example, biologically potent differential outcomes (e.g., food and no-food) may differ markedly in hedonic value. Accordingly, it can be assumed that the sample associates of two nonhedonic outcomes will not engender systematically different patterns of responding.

To my knowledge, there are no published accounts of DOEs using nonhedonic outcomes in a DMTS task with nonhuman organisms. Nevertheless, effects have been observed with pigeons in a delayed *spatial* discrimination procedure in which two delivery sites, upper and lower, for the same grain reinforcement were used as the nonhedonic outcomes (Williams, Butler, & Overmier, 1990). In that procedure, birds were required to respond correctly to one of two simultaneously presented and spatially distinct yellow pecking keys depending on which color, green or red, had occurred as the initial stimulus on a centrally located key at the beginning of the trial. Subjects in the DO condition, for which there was a perfect correlation between correct stimulus-response sequence and site of reinforcement delivery, demonstrated faster acquisition, higher overall accuracy, and better retention over a wide range of test delays, compared to subjects in the NDO condition, for which there was a zero correlation between correct sequence and site of reinforcement delivery.

Although the nonhedonic DOEs reported in this study are certainly suggestive of a role for central expectancies in nonhuman animals, use of spatially differentiated outcomes complicates interpretation of the data. In particular, it is possible that the DOEs reported by Williams et al. (1990) resulted from conditional goal-tracking responses in the DO condition, but not in the NDO condition. Specifically, because the nonhedonic outcomes were spatially distinct in the DO condition, each of the two initial stimuli may have come to elicit a unique goal-tracking response. For example, presentation of the green initial stimulus may have come to elicit an orienting response to, say, the upper grain-delivery site (i.e., where grain would occur following a correct "green" response), and presentation of the red initial stimulus may have come to elicit

orientation to the lower grain-delivery site (i.e., where grain would occur following a correct "red" response). Consequently, these unique goal-tracking responses might have provided salient differential proprioceptive stimuli that, in turn, could have come to control accurate responding in the DO condition. Note that such cues would have been unavailable to subjects in the NDO condition because for these birds, both initial stimuli were equally associated with reinforcement at both grain-delivery sites. Consequently, conditional goal-tracking responses could not have developed and, hence, differential proprioceptive cues would not have been available to control accurate discrimination performance in the NDO condition.

The DMTS task, as a *nonspatial* procedure, provides an excellent tool to more clearly investigate the role of central expectancies in nonhedonic DOEs. As indicated previously, over DMTS trials with each of the two samples, reinforcement always occurs at the same delivery sight. Consequently, conditional goal-tracking responses cannot develop in the DO condition and, hence, proprioceptive cues resulting from explicit orientation responses should be no more likely to mediate accurate performance in the DO condition as in the NDO condition.

With this feature in mind, the DMTS task was recently modified to investigate nonhedonic DOEs in pigeons (Kelly, 1997; Kelly & Grant, 1998). In this procedure, birds were exposed to line-orientation samples and test stimuli (i.e., horizontal and vertical), and received biologically irrelevant color events (i.e., blue and yellow) as nonhedonic outcomes, followed by a biologically potent event (i.e., food). Each correct sample-response sequence (i.e., horizontal-horizontal, and vertical-vertical) resulted in a brief (e.g., 3 s) presentation of a nonhedonic color outcome (either blue or yellow) on the

center key, and concluded with a brief (e.g., 3 s) presentation of food, followed by the ensuing ITI which contacted the next trial. Alternatively, each incorrect sequence (i.e., horizontal-vertical, and vertical-horizontal) resulted in immediate termination of the trial (i.e., prevented delivery of the color outcome and food on that trial), and the ensuing ITI concluded in a repeat of the trial (i.e., a correction trial). For subjects in the DO condition, correct sample-response sequence was perfectly correlated with color outcome, whereas subjects in the NDO condition experienced a zero correlation between correct sequence and color outcome.

In Experiment 1, this basic DMTS procedure was elaborated to compare hedonic and nonhedonic DOEs during acquisition, extended-delay performance, and transfer to a novel task with pigeons. In Experiment 2, additional procedural modifications were devised and "multidimensionally-different" nonhedonic outcomes (i.e., red and no red) were used, to investigate conditions under which stronger nonhedonic DOEs might be obtained. In Experiment 3, these procedural modifications were employed to reevaluate nonhedonic DOEs with "unidimensionally-different" nonhedonic outcomes (i.e., red and green), and to test a "secondary-reinforcement" account of nonhedonic DOEs with red and no-red outcomes.

Experiment 1

Birds were exposed to horizontal and vertical samples and test stimuli, and received color events (green and red) as nonhedonic outcomes, followed by biologically potent events (food and no food) as hedonic outcomes. Each correct sample-response sequence resulted in a 3-s presentation of a color outcome on the center key, followed by a 3-s presentation of an hedonic outcome in the illuminated magazine opening, and

concluded with the ITI. Alternatively, each incorrect sequence resulted in immediate termination of the trial, and the trial was repeated following the ensuing ITI.

Three conditions were established in this experiment (see Table 2). First, in an *hedonic differential outcome* (HDO) condition, there was a zero correlation between correct sample-response sequence and nonhedonic color outcome, and a perfect correlation between correct sequence and hedonic outcome. Second, in a *color differential outcome* (CDO) condition there was a perfect correlation between correct sample-response sequence and color outcome, and a zero correlation between correct sequence and hedonic outcome. Third, in an NDO condition, there was a zero correlation between correct sample-response sequence and both color and hedonic outcome.

Behavioral-mediation theory predicts strongest DMTS performance in the HDO condition. Due to the perfect correlation between correct sample-response sequence and hedonic outcome, and because of the extreme difference in hedonic value of the food and no-food outcomes, marked differences in patterns of responding should come to be activated by presentation of the two line samples. Thus, highly distinct, discriminable, and memorable proprioceptive stimuli should provide a discriminative basis for correct test stimulus responding, in addition to cues provided by sensory representations of the line samples. Similarly, expectancy theory also predicts strongest performance in the HDO condition. Highly distinct, discriminable, and memorable central representations of the hedonic outcomes should also come to be differentially activated by presentation of the two line samples. Thus, differential outcome expectancies of food and no food should also provide a discriminative basis for correct test stimulus responding.

In the NDO condition, neither differential proprioceptive cues nor differential

expectancies would be available to facilitate performance. Therefore, both behavioral-mediation theory and expectancy theory predict weaker performance in the NDO condition compared to the HDO condition. Due to the zero correlation between correct sample-response sequence and both color and hedonic outcomes, neither differential outcome expectancies nor differential patterns of responding should come to be activated by presentation of the two line samples. Hence, performance in the conditional discrimination could be controlled only by the less distinctive, less discriminable, and less memorable sensory features of the line stimuli. However, because behavioral-mediation theory posits a simpler mechanism than expectancy theory, stronger performance in the HDO condition than in the NDO condition would be most parsimoniously explained on a simpler behavioral-mediation process and an appeal to a more complex expectancy process is unnecessary.

Finally, the two theories tend to diverge in their predictions for DMTS performance in the CDO condition. Due to the perfect correlation between correct sample-response sequence and color outcome, expectancy theory predicts that a unique central representation of a color outcome will come to be activated by presentation of each of the two line samples. If an expectancy of a color outcome is more distinct, discriminable, and memorable (Carter & Eckerman, 1975; Farthing, Wagner, Gilmour, & Waxman, 1977), and provides a more effective discriminative cue, than the sensory features of a line stimulus alone, then expectancy theory anticipates stronger performance in the CDO condition compared to the NDO condition, in which there is a zero correlation between correct sequence and color outcome. Nevertheless, if an expectancy of a color outcome is less distinct, discriminable, and memorable (e.g., Maki, Moe, &

Bierly, 1977; Wilkie, 1978), and provides a less effective discriminative cue, than an expectancy of an hedonic outcome and/or the proprioceptive cues that result from differential sample responding (e.g., Urcuioli, 1985; Urcuioli & Honig, 1980), then performance in the CDO condition should be somewhat weaker compared to the HDO condition.

It is important to recognize that there is no *a priori* reason to anticipate that CDO and NDO conditions should differ in magnitude of differential sample responding. Specifically, differential responding to the line-sample associates of the green and red color outcomes in the CDO condition should not differ from differential responding to the line samples in the NDO condition. Consequently, differential proprioceptive stimuli should be equally available to subjects in these 2 conditions. Accordingly, behavioral-mediation theory would anticipate equivalent performance in the CDO and NDO conditions. In Experiment 1, these contrasting predictions of behavioral-mediation theory and expectancy theory for performance in the HDO, CDO, and NDO conditions were examined in each of the three possible indicants of the DOE: Acquisition of the DMTS task, accuracy of DMTS performance under conditions of extended delays, and transfer of performance to a novel procedure, in which the color and hedonic outcomes themselves were substituted for the line samples in the DMTS task.

Method

Subjects

Fifteen experimentally naive Silver King pigeons (*Columba livia*), each approximately six months old, served in this experiment ($N = 15$). First, two weeks of unrestricted access to mixed grain was provided to determine birds' free-feeding weights.

Then, over the next two weeks, each subject's weight was gradually reduced to 80% of its free-feeding value. Thereafter, reinforcement obtained during experimental sessions, supplemented by post-session feedings if necessary, maintained each bird's weight at this level. Between sessions, birds were housed individually in wire-mesh cages and were given unrestricted access to water and health grit. Home cages were kept in a common colony room, illuminated on a diurnal schedule (12-hr light/12-hr dark) with light onset at 0600 hrs.

Apparatus

Procedures were conducted in 8 identical operant chambers, each measuring 29.0 x 29.0 x 24.0 cm (height x length x width). In each chamber, a horizontal alignment of three circular pecking keys (each 2.5 cm in diameter, and with side keys separated edge-to-edge from the center key by 3.0 cm) was centered along one end wall. The key alignment was raised 22.5 cm from the barred-floor base of the chamber. Affixed behind each key was an Industrial Electronics, Inc. (Van Nuys, CA) in-line projector. Projectors were capable of transilluminating a 0.7-cm wide white line, in a horizontal or vertical orientation, which bisected a black background on the key. In addition, the center-key projector could transilluminate a homogeneous field of green or red, as well as a white 0.3-cm ("small") circle centered on a black background. A force greater than 0.15 N applied to any key was recorded as a keypeck. The top edge of a 5.0-cm wide x 5.5-cm high rectangular opening, oriented perpendicular to the floor, was located 9.0 cm directly beneath the edge of the middle key. This opening, centered horizontally along the end wall, provided access to a retractable food magazine. A 28-v lamp, recessed within the magazine opening, could be activated independent of the food magazine. Each chamber

was enclosed in a sound- and light-attenuating booth. Within each booth, an exhaust fan provided ventilation and, supplemented by an external white noise generator, contributed masking auditory stimulation. All experimental booths were isolated in the same darkened running room. Experimental events were controlled from, and responses were recorded to, a microcomputer located in an adjoining room.

Birds were randomly assigned to one of three experimental groups, hedonic differential outcomes (HDO), color differential outcomes (CDO), and nondifferential outcomes (NDO), with a restriction of equivalent group sizes (*n*s = 5). Throughout this experiment, sessions were given in 2 squads of 7 or 8 animals. Over days, the squads were run sequentially in the same order beginning at approximately the same time each morning. Sessions were conducted 6 to 7 days per week, and each bird always received its sessions in the same experimental chamber.

Procedure

0-s DMTS Acquisition. Eight sessions of magazine training and autoshaping were provided. When reliable feeding from the food hopper and keypecking of the stimuli on all 3 keys was observed, preliminary training was discontinued.

Next, subjects were required to accurately match horizontal and vertical side-key test stimuli to horizontal and vertical center-key samples. Each trial began with presentation of the small circle as a preparatory ("trial ready") stimulus on the center key. Either a single peck to the circle or the passage of 5 s, whichever occurred first, terminated this stimulus and was followed immediately by presentation of a horizontal or vertical sample. On each trial, both samples were equally likely, with a restriction of equivalent numbers of horizontal and vertical sample presentations within each session.

Sample termination was followed immediately (i.e., 0-s delay) by presentation of the horizontal test stimulus on one side key and the vertical test stimulus on the remaining side key. A single peck to either test stimulus terminated both. For all subjects, a peck to the horizontal test stimulus after the horizontal sample, and a peck to vertical after vertical, were designated as correct choices (i.e., identity-matching). A correct choice produced a 3-s color outcome on the center key, either a green or red stimulus. Subsequently, the color outcome terminated in a 3-s hedonic outcome, either illuminated presentation of the food hopper ("food") or illumination of the hopper opening unaccompanied by presentation of food ("no food"). Finally, a dark 15-s intertrial interval (ITI) ensued, at which time the next trial of the session was presented.

Conversely for all subjects, a peck to the vertical test stimulus after the horizontal sample, and a peck to horizontal after vertical, were designated as incorrect choices. An incorrect choice produced a timeout equivalent to the summed durations of the color and hedonic outcomes (i.e., 6 s), followed by the darkened 15-s ITI, and then a repeat of the trial in which the incorrect choice occurred (i.e., complete-trial correction procedure). Responses on correction trials were not recorded, but correct choices on such trials resulted in a color outcome followed by a hedonic outcome, according to group conditions (see below). Incorrect responses on correction trials merely reinitiated the correction cycle. Over trials within each session, the left/right side-key location of the correct test stimulus varied randomly with the restriction that, within a session for each line sample, the correct test stimulus appeared equally often on the left and right key.

Groups differed in terms of the correlations between correct choices, and the color and hedonic outcomes that followed. In group HDO, although there was a zero

correlation between correct choice and color outcome, there was a perfect correlation between correct choice and hedonic outcome. Thus, for all animals in this group, correct choice of both horizontal and vertical test stimuli was as likely to be followed by a green as by a red color outcome. However, for 3 subjects, the color outcome following a correct horizontal choice always terminated in the food hedonic outcome, and the color outcome following a correct vertical choice always terminated in the no-food hedonic outcome. For the remaining 2 subjects, these relations were reversed.

In group CDO, there was a perfect correlation between correct choice and color outcome, whereas there was a zero correlation between correct choice and hedonic outcome. Thus, for 3 subjects in this group, correct choice of the horizontal test stimulus always produced the red color outcome and correct choice of the vertical test stimulus always produced the green color outcome. For the remaining 2 subjects, these relations were reversed. However, each color outcome was as likely to be followed by a food as by a no-food hedonic outcome.

Finally, in group NDO, there was a zero correlation between correct choice and both color and hedonic outcome. Thus, correct choice of the horizontal test stimulus was as likely to be followed by a green as by a red color outcome, which was then as likely to terminate in a food or no-food outcome. In addition, correct choice of vertical was equally likely to produce a green or red outcome, which was then equally likely to terminate in a food or no-food outcome.

Each session consisted of 64 trials, and each subject was given at least 10 sessions of training. Performance within each session was evaluated by computing percentage (%) of correct horizontal choices to total horizontal-sample trials, and of correct vertical

choices to total vertical-sample trials. Acquisition was defined as correct choice of 80% or greater on both trial types for 2 consecutive sessions, including sessions 9 and 10. In addition to choices, number of keypeck responses to each of the 2 line samples were recorded, and rates of responding (keypecks per second) were computed. By the end of session 30, 1 subject in each of the 3 groups (Birds 701, 706, and 711 in groups HDO, CDO, and NDO, respectively) had failed to meet acquisition criteria. Hence, after session 30 for these 3 birds, the ITI following an incorrect match was doubled from 15 to 30 s to impose a greater penalty for incorrect choices.

Extended-Delay Testing. As each subject met acquisition criteria, it was immediately moved to extended-delay testing. Test sessions were identical to those of 0-s DMTS acquisition, with the following exceptions. Within each session, the 0-s delay of training occurred on only 75% of trials, and each of 2 extended delays occurred on 12.5% of trials. The 3 types of delay trials occurred randomly within sessions, with the restriction of equivalent numbers of horizontal and vertical sample presentations at each level of delay, counterbalanced for location of the correct test stimulus. The correction procedure remained in effect, to prevent generalization decrement that might have resulted from its removal (i.e., "novelty" effects). However, if an incorrect choice occurred on an extended-delay trial, the correction trial replaced the extended delay with the 0-s training delay. This was done to prevent additional exposure to the extended delays. Finally, as before, responses on correction trials were not recorded, but correct choices on such trials resulted in a color outcome followed by a hedonic outcome, according to group conditions (see Table 2).

Extended-delay testing was conducted in 2 phases. Extended delays were 1 and 3

s in the first phase, and 2 and 6 s in the second phase. In each phase, 2 consecutive replications of 4 consecutive sessions were provided. In each replication, performance was evaluated by computing % correct choices over all trials at each of the 3 delays. In addition, rates of responding to each of the 2 line samples, collapsed over the delay factor, continued to be computed. Upon completion of the first extended-delay test phase, the ITI following an incorrect match for Birds 701, 706, and 711 was returned to 15 s. Twelve consecutive sessions of baseline training, identical to sessions of 0-s DMTS acquisition, were interpolated between the 2 test phases. This training was given to maintain accurate performance on the 0-s DMTS task. Over the final 4 sessions of interpolated baseline training, mean % correct in groups HDO, CDO, and NDO were, respectively, 97.4 (range = 90.6 to 100.0), 93.2 (range = 84.4 to 96.9), and 92.3 (range = 85.2 to 98.4).

Transfer Testing. Before this phase of the experiment, birds had received several further stages of training and extended-delay testing. However, results from these interim stages were not informative, and thus are not presented.

Immediately prior to transfer testing, subjects were provided with at least 8 consecutive sessions of baseline training to ensure continued accurate performance on the 0-s DMTS task. Sessions were identical to those of 0-s DMTS acquisition, except that the duration of the color outcomes was increased from 3 to 5 s and, accordingly, the duration of the timeout following an incorrect choice was increased from 6 to 8 s. In addition, one subject in group HDO (Bird 711) had difficulty completing trials in which choice of the no-food associated test stimulus was correct, presumably because correct responses on these trials always resulted, after the color outcome, in the unfavorable no-

food outcome. Thus for this subject, the probability of the food outcome on trials in which the no-food associated test stimulus was correct was increased, from 0 to 0.2. In addition, to maintain an overall rate of reinforcement for this subject that was equivalent to other subjects, the probability of the food outcome on trials in which the food-associated test stimulus was correct was decreased, from 1.0 to 0.8. These procedures were successful in restoring accurate performance in this subject. Over the final 4 sessions of baseline training, mean % correct in groups HDO, CDO, and NDO were, respectively, 94.1 (range = 77.7 to 99.6), 90.5 (range = 78.5 to 94.1), and 93.1 (range = 89.1 to 96.1).

Two types of transfer test sessions were constructed: An hedonic transfer session and a color transfer session. The hedonic transfer session was identical to a session of 0-s DMTS acquisition, except that 3-s food and no-food transfer samples replaced the usual horizontal and vertical samples. For each subject in group HDO, correct (and incorrect) choices during the hedonic transfer session were defined so as to be consistent with the associations between correct choices and hedonic outcomes which that subject experienced during baseline training. For instance, if, during training, a correct horizontal choice resulted (after the color outcome) in the food hedonic outcome and a correct vertical choice resulted (after the color outcome) in the no-food hedonic outcome, then, during testing, a horizontal choice was considered correct (and a vertical choice was considered incorrect) after a food transfer sample and a vertical choice was considered correct (and a horizontal choice was considered incorrect) after a no-food transfer sample. Additionally, individual subjects in groups CDO and NDO were yoked to subjects in group HDO. Thus, a given subject in group CDO and a given subject in

group NDO experienced identical contingencies as its yoked counterpart in group HDO during the hedonic transfer session. In this way, the hedonic transfer session constituted positive transfer for subjects in group HDO and neutral transfer for subjects in groups CDO and NDO.

In similar fashion, the color transfer session was identical to a session of 0-s DMTS acquisition, except that 5-s green and red transfer samples on the center key replaced the usual horizontal and vertical samples. For each subject in group CDO, correct (and incorrect) choices during the color transfer session were defined so as to be consistent with the associations between correct choices and color outcomes which that subject experienced during baseline training. For instance, if, during training, a correct horizontal choice resulted in the green outcome and a correct vertical choice resulted in the red outcome, then, during testing, a horizontal choice was considered correct (and a vertical choice was considered incorrect) after a green transfer sample and a vertical choice was considered correct (and a horizontal choice was considered incorrect) after a red transfer sample. Additionally, subjects in groups HDO and NDO experienced identical contingencies as its yoked counterpart in group CDO during the color transfer session. In this way, the color transfer session constituted positive transfer for subjects in group CDO and neutral transfer for subjects in groups HDO and NDO.

During transfer testing, all correct choices resulted in a color outcome (equiprobably green or red) followed by an hedonic outcome (equiprobably food or no food). Note that during both types of transfer sessions for all 3 groups, there was a zero correlation between correct choice and both color and hedonic outcome. All incorrect choices resulted in an 8-s timeout (i.e., the combined durations of the 5-s color and 3-s

hedonic outcomes), followed by a 30-s ITI (i.e., a doubling of the usual 15-s ITI), and then a repeat of the trial in which the incorrect choice occurred (i.e., the correction procedure remained in effect). As before, responses on correction trials were not recorded, but correct choices on such trials produced nondifferential color and hedonic outcome events, as on noncorrection trials. Trials within each transfer session were blocked into 4 consecutive blocks of 16 trials per block. Each block consisted of 4 presentations of each of the 4 possible trial types (2 transfer samples x 2 left/right locations of the line test stimuli), presented in random order.

Performance within each block of each of the 2 types of transfer sessions was evaluated by computing % correct choices over all trials of that block. In addition to choices, rates of responding to each of the 2 color samples during the color transfer session were computed. (Note, of course, that response rates to each of the 2 hedonic samples during the hedonic transfer session could not be recorded.)

Order of presentation of the 2 types of transfer sessions was counterbalanced within each group. Hence, in groups CDO and NDO, 3 birds experienced the color transfer session first and the hedonic transfer session second, whereas 2 birds experienced transfer sessions in the reverse order. In group HDO, 3 birds experienced the hedonic transfer session first and the color transfer session second, whereas 2 birds experienced transfer sessions in the reverse order. For all subjects, 4 consecutive sessions of baseline training was interpolated between the 2 transfer sessions, to ensure continued accurate performance on the 0-s DMTS task. One subject in group HDO (Bird 713) failed to respond in its first transfer session, which was the color transfer session. Thus, following completion of its hedonic transfer session, 12 consecutive sessions of baseline training

were provided, followed by a repeat of the color transfer session. This procedure was successful in initiating responding in this subject's color transfer session. In addition, one subject in group CDO (Bird 704) began, but did not fully complete, the fourth block of trials in its hedonic transfer session.

Results and Discussion

Throughout this study, $\alpha = .05$ was used to define the region for rejection of the null hypothesis.

0-s DMTS Acquisition. In general, acquisition appeared to be fastest in group HDO, moderately slower in group CDO, and slowest in group NDO. Mean sessions required to meet acquisition criteria in groups HDO, CDO, and NDO, respectively, were 15.4 (range = 10 to 32), 22.6 (range = 10 to 53), and 24.6 (range = 11 to 62). However, a one-way analysis of variance (ANOVA) on these data failed to return a significant effect for group.

Similarly, accuracy across sessions also indicated that acquisition was fastest in group HDO, moderately slower in group CDO, and slowest in group NDO. Figure 1 shows rates of acquisition in the 3 groups over the first 10 sessions of training, the only sessions from which there were data for all subjects. However, as before, a split-plot ANOVA on these data failed to return significant group or Group x Session terms. However, the main effect for session was significant, $F(9,108) = 48.43$, indicating higher accuracy in later than in earlier sessions.

Accuracy in the final session of acquisition for each subject was highest in group HDO ($M = 94.4$, range = 90.6 to 98.4), and was slightly lower in groups NDO ($M = 91.2$, range = 85.9 to 95.3) and CDO ($M = 89.4$, range = 84.4 to 93.7). However, a one-way

ANOVA failed again to return a significant effect for group.

Finally, a sample discrimination ratio (SDR) was computed as an index of the degree to which differential sample responding had developed. For each subject's final session of acquisition, the response rate on the line-orientation sample to which responding was most rapid was divided by the sum of the response rates to the 2 samples. Hence, an SDR of .5 indicates nondifferential sample responding (i.e., equivalent rates of responding to the 2 line-orientation samples), and an SDR approaching the limit (1.0) indicates increasingly differential sample response rates. SDR was much higher in group HDO (M = .94, range = .89 to 1.00) than in groups CDO (M = .64, range = .53 to .87) and NDO (M = .62, range = .51 to .82). The sample to which responding was most rapid was the food-associated line orientation for 5 of 5 subjects in group HDO, the green-associated line orientation for 3 of 5 subjects in group CDO, and the horizontal line orientation for 2 of 5 subjects in group NDO. The remaining subjects in groups CDO and NDO responded more rapidly to the alternate sample. A one-way ANOVA on SDR data indicated a significant group effect, $F(2,12) = 12.92$, and *a posteriori* multiple comparisons (Duncan's test) indicated that SDR was greater in group HDO than in groups CDO and NDO, which did not differ.

In general, results of 0-s DMTS acquisition provided, at best, only weak evidence of a nonhedonic DOE, in that there was only a slight and nonsignificant trend toward stronger acquisition in group CDO than in group NDO. Although this tendency suggests that differential outcome expectancies of nonhedonic events facilitated acquisition of the DMTS task, the advantage of these expectancies was marginal. It is possible that the salient hedonic outcomes overshadowed the color outcomes for some animals in group

CDO. Thus, perhaps failure of 2 or 3 subjects in group CDO to detect the availability of the differential color outcomes slowed acquisition in this group. Alternatively, it is possible that the addition of color outcome expectancies in group CDO provided a discriminative cue that was only slightly more effective than sensory representations of line stimuli in group NDO. Hence, use of color outcome expectancies in group CDO would be difficult to distinguish from use of sensory features of lines in group NDO.

Perhaps more surprising was the lack of an advantage in acquisition for group HDO. This observation is in contrast to the hedonic DOE in pigeons that is typically seen in acquisition of a DMTS task with food and no-food outcomes. Nevertheless, trends in the present data were in the direction of the expected advantage for group HDO, and the failure of this advantage to reach significance may be related to relatively rapid acquisition of the task for most subjects in all 3 groups. In addition, operation of a ceiling artifact may have disguised the extent to which acquisition in group HDO surpassed that in groups CDO and NDO. Finally, because hedonic outcomes were delayed by 3 s after a correct choice (i.e., the duration of the color outcome), the effect of differential hedonic outcomes may have been reduced in magnitude.

Notwithstanding the nonsignificant group differences in acquisition, analysis of SDR data are consistent with use of behavioral mediation in group HDO, and are not inconsistent with use of expectancies in group CDO. A marked degree of differential sample responding was observed in group HDO. Consequently, distinct and discriminable proprioceptive stimuli were likely available to facilitate 0-s DMTS acquisition. By contrast, the modest differential sample responding in groups CDO and NDO was very similar. Presumably, these latter 2 groups did not differ in the extent to

which discriminative peripheral cues were available, and differed only in the extent to which discriminative expectancies of the nonhedonic outcomes were available. Hence, what little advantage there was for group CDO over group NDO in acquisition was likely due to use of differential outcome expectancies of green and red that were available to group CDO but not to group NDO.

Extended-Delay Testing. Patterns of retention were virtually identical in both replications of both extended-delay testing phases. Figure 2, upper and lower panels, shows percent correct as a function of increasing delay for the first and second extended-delay test phases, respectively, collapsed over replications. In both phases, accuracy was high and relatively stable in group HDO, but declined precipitously in groups CDO and NDO.

Separate split-plot ANOVAs were conducted on each phase of extended-delay testing, and returned identical results. All terms involving the replication factor were nonsignificant. In both the first and second phases, there were significant main effects of group, respective Fs(2,12) = 23.03 and 71.98, and of delay, respective Fs(2,24) = 54.00 and 119.19, and the Group x Delay interaction was significant in both phases as well, respective Fs(4,24) = 6.72 and 22.14.

The interaction terms were further explored with multiple comparisons, and indicated the absence of group differences in accuracy at the 0-s delay in either extended-delay test phase. However, group HDO was more accurate than groups CDO and NDO, which did not differ, at both extended-delays in both phases of testing.

Mean group SDRs for each phase of testing, collapsed over replication, were computed. In the first phase, mean SDR was much higher in group HDO (M = .94, range

= .86 to .99) than in groups CDO (M = .63, range = .51 to .77) and NDO (M = .59, range = .52 to .66). The sample to which responding was most rapid was the food-associated line orientation for 5 of 5 subjects in group HDO, the green-associated line orientation for 2 of 4 subjects in group CDO (1 subject responded at equal rates to the green- and red-associated line orientations), and the horizontal line orientation for 3 of 5 subjects in group NDO. The remaining subjects in groups CDO and NDO responded more rapidly to the alternate sample. A one-way ANOVA on SDR data returned a significant main effect for group, $F(2,12) = 37.15$, and multiple comparisons indicated that SDR was greater in group HDO than in groups CDO and NDO, which did not differ.

In the second phase of testing, SDRs were again much higher in group HDO (M = .94, range = .88 to 1.00) than in groups CDO (M = .63, range = .53 to .72) and NDO (M = .59, range = .51 to .79). The sample to which responding was most rapid was the food-associated line orientation for 5 of 5 subjects in group HDO, the green-associated line orientation for 4 of 5 subjects in group CDO, and the horizontal line orientation for 3 of 5 subjects in group NDO. The remaining subjects in groups CDO and NDO responded more rapidly to the alternate sample. A one-way ANOVA on SDR data returned a significant main effect for group, $F(2,12) = 23.23$, and multiple comparisons again indicated that SDR was greater in group HDO than in groups CDO and NDO, which did not differ.

In general, the availability of nonhedonic differential outcomes failed to facilitate retention performance in group CDO, compared to group NDO. Thus, extended-delay test results failed to provide any evidence consistent with an expectancy account of the DOE on working memory performance.

As anticipated and in contrast to findings of 0-s DMTS acquisition, group HDO showed a marked advantage in retention, compared to groups CDO and NDO. In fact, at the longest delay in both phases of testing, accuracy was only slightly reduced from that observed at the 0-s delay in group HDO, well above 50% chance performance. Thus, as demonstrated in a number of previous studies, the availability of differential hedonic outcomes supported very strong retention performance in pigeons. Moreover, the advantage obtained despite the 3-s delay (i.e., the duration of the color outcome) that preceded the hedonic outcome.

Nevertheless, both formal and casual observations suggested that behavioral mediation may provide an adequate explanation for strongest retention in group HDO. Formally, subjects in this group demonstrated much higher levels of differential sample responding, compared to subjects in the remaining two groups. Casually, higher levels of differential sample responding were also seen in nonrecorded aspects of behavior in group HDO. Specifically, on trials in which the food-associated sample occurred, birds in group HDO typically chose (usually correctly) with minimal latencies, whereas on trials in which the no-food-associated sample occurred, birds often chose (again, usually correctly) with extended latencies. Indeed, on these latter types of trials, the latency to choose was sometimes on the order of minutes! Such differential latencies to respond were never observed in groups CDO or NDO. Thus, better retention in group HDO may be attributable to differential sample responding and differential latencies to test stimulus choice.

Accordingly, for group HDO, presentation of the food-associated sample activated one behavioral state (e.g., approach, pecking, agitated excitement, etc.) and

presentation of the no-food-associated sample activated a second behavioral state (e.g., avoidance, exploration of the chamber, frustration, etc.). These states, and the unique stimulus feedback they provided, appeared to be very persistent. Indeed, feedback from behaviors activated by the no-food-associated sample at times must have lasted several minutes. Nevertheless, very accurate choices were made. As discussed in the introduction, it is very likely that differential behaviors activated by the samples in group HDO resulted from the extreme difference in hedonic value of food and no-food outcomes. This mechanism could not have operated in groups CDO and NDO, for which both line samples were equally associated with the food and no-food outcomes.

Transfer Testing. In the color transfer session, total % correct was virtually equivalent in groups CDO (M = 58.8, range = 46.9 to 75.0) and HDO (M = 57.5, range = 39.1 to 75.0), and moderately lower in group NDO (M = 49.1, range = 42.2 to 56.3). Additionally, % correct appeared to be constant over blocks of trials in groups HDO and NDO, and appeared to increase over blocks in group CDO (Fig. 3, upper panel). Still, a split-plot ANOVA on % correct data failed to return reliable group, block, or Group x Block terms. Mean group SDRs for the color transfer test session were computed, and turned out to be very similar in groups HDO (M = .64, range = .53 to .79) and NDO (M = .63, ranges = .57 to .71), and moderately lower in group CDO (M = .58, range = .51 to .65), and a one-way ANOVA on SDR data failed to return a significant main effect for group. The green transfer sample was responded to more rapidly by 2 of 5 subjects in group HDO, 1 of 5 subjects in group NDO, and 2 of 5 subjects in group CDO. The remaining subjects in each group responded more rapidly to the red transfer sample.

Results of the color transfer test session provided very little evidence in favor of

expectancy theory. Although group CDO demonstrated a tendency for accuracy to increase over blocks of trials and demonstrated highest overall accuracy in the test session, performance did not significantly differ from that observed in groups HDO and NDO. Expectancy theory suggests that expectancies of nonhedonic outcomes in group CDO should mediate performance in a novel DMTS task that presented those nonhedonic events as transfer samples. Specifically, presentation of a particular outcome, green or red, as a transfer sample during testing, should have tended to control choice of the specific line-orientation test stimulus that, during training, had resulted in that particular color event as the outcome. Presumably, such control would have been mediated by expectancies of the color outcomes that corresponded to the color transfer samples and, as a result, positive transfer should have been possible in group CDO. This expectancy-mediation process could not have operated in groups HDO and NDO because, during training, the green and red color outcomes had been equally associated with correct choice of both line-orientation test stimuli. Consequently, during testing, presentation of either color transfer sample would have equally controlled choice of both line-orientation test stimuli.

At most, however, the transfer effect of nonhedonic differential outcomes was weak and did not reach levels of statistical reliability. As indicated previously, the weakness of the effect in the color transfer session could have been due to the failure of some group CDO birds to detect the differential color outcomes during original training. If so, these birds would have lacked the necessary outcome expectancies for mediation of accurate matching in the color transfer session. Consequently, their performance would have suppressed positive transfer in group CDO as a whole.

In the hedonic transfer session, total % correct was greatest in group HDO (M = 67.5, range = 62.5 to 70.3), moderately lower in group NDO (M = 62.8, range = 57.8 to 68.7), and lower still in group CDO (M = 55.1, range = 39.1 to 60.9). Trends in % correct over blocks of trials appeared to be unsystematic in groups HDO and NDO, and appeared to increase over blocks in group CDO (Fig. 3, lower panel). A split-plot ANOVA on % correct data failed to return reliable block or Group x Block terms, but the group effect was significant, $F(2,12) = 5.67$. Multiple comparisons indicated greater total % correct in group HDO than in group CDO.

Results of the hedonic transfer test session were clearer, in that group HDO showed statistically stronger performance, at least in comparison to group CDO. This finding is consistent with behavioral-mediation theory, according to which differential sample behaviors that originally come to be activated by the line-sample associates of the hedonic outcomes, can subsequently mediate performance in a novel DMTS task that presents those hedonic events as transfer samples. Specifically, presentation of the hedonic outcomes (food and no food) as transfer samples tended to activate differential patterns of behavior (respectively, pecking food *versus* not pecking no food) that were highly similar to the differential patterns of behavior that had come to be activated by the line-orientation samples (pecking the sample *versus* not pecking the sample) during original training. Consequently, differential feedback cues that came to control correct choice of line-orientation test stimuli during training, were largely available to control correct choices during the hedonic transfer session. As a result, positive transfer was possible in group HDO. This behavioral-mediation process could not operate in groups CDO and NDO because, during training, the food and no-food hedonic outcomes

occurred equally often (following the color outcome) after correct choice on trials with both line-orientation samples. Thus, both samples would have come to activate the same pattern of behavior. Consequently, during the hedonic transfer test, the differential patterns of behavior activated by the food and no-food transfer samples could not produce correct choices.

Overall, results of the present experiment provide moderately strong support for behavioral-mediation theory. Throughout acquisition, extended-delay testing, and hedonic transfer, performance in group HDO was generally stronger than that in groups CDO and NDO, although comparisons were not always statistically reliable. In contrast, results provide marginal support, at best, for expectancy theory. In only some comparisons, did group CDO performance correspond to predictions of expectancy theory. Moreover, none of these comparisons reached levels of statistical significance. Evidently, nonhedonic differential outcome expectancies appeared to provide a discriminative cue that was only marginally more discriminable, and no more memorable, than the sensory features of line-orientation stimuli. Additionally, such expectancies failed to provide effective mediators of transfer to a novel procedure in which those nonhedonic events were presented as transfer samples.

Experiment 2

The presence of merely suggestive evidence for nonhedonic DOEs in Experiment 1 was not unprecedented. Pilot studies conducted in our laboratory (Kelly, 1997; Kelly & Grant, 1998) have investigated alternate nonhedonic differential outcomes (e.g., blue and yellow colors, rather than green and red), under a variety of experimental conditions (e.g., using a fixed, nonzero delay, rather than a 0-s delay, between sample offset and onset of

test stimuli during acquisition; presenting the color outcome on the chosen key, rather than on the center key; presenting the color outcome on a fixed-interval, rather than on a fixed-time, schedule; presenting food after 100% of color outcomes, rather than after only 50% of color outcomes). Generally, a nonhedonic DOE has been observed in acquisition of the DMTS task but not during extended-delay testing. Moreover, faster acquisition in the DO condition than in the NDO condition has not always been statistically significant. (Transfer performance not was evaluated in any of these pilot studies.)

Perhaps the events chosen as nonhedonic outcomes in pilot studies and in Experiment 1 were simply not sufficiently differential to pigeons. Specifically, the two colors that have been used as nonhedonic outcomes differed primarily along only a single stimulus dimension, i.e., visual wavelength. It should be noted that effective hedonic outcomes, such as food and water, typically differ multidimensionally. For example, food and water certainly have marked differences in their visual, gustatory, and tactile features. Perhaps pigeons find events that differ multidimensionally easier to differentiate. If so, then stronger nonhedonic DOEs and, hence, stronger evidence in favor of expectancy theory, might be more likely to result from use of multidimensionally-different nonhedonic outcomes. Experiment 2 was designed to investigate this possibility.

The presence of a nominally nonhedonic event (e.g., presence of a red stimulus on a key) and the absence of that event (i.e., absence of the red stimulus on that key) have been shown to be highly discriminable as samples in a DMTS task with pigeons (e.g., Colwill, 1984; Grant, 1991; Sherburne & Zentall, 1993a, b, 1995a; Wilson & Boakes, 1985; Wixted, 1993). A reasonable case can be made that such nonhedonic events

exhibit multidimensional differences. To elaborate, red and no-red events probably differ along several visual dimensions; wavelength, brightness, saturation, and spatial differences, to name a few. Presumably, these multidimensionally-different nonhedonic events should prove highly differential as outcomes.

In the present experiment, red and no-red events were programmed as nonhedonic outcomes (see Table 3). Thus, for birds in group *multidimensional differential outcomes* (MDO), one type of correct sample-response sequence always resulted in the brief presence of a red stimulus (the "red" outcome), whereas a second type of correct sample-response sequence always resulted in the brief absence of a red stimulus (the "no-red" outcome). By comparison for birds in group NDO, both types of correct sample-response sequences resulted equally often in red and no-red outcomes. In short, the correlation between sample-response sequence and nonhedonic outcome was perfect in group MDO and zero in group NDO. Finally, for both groups, each of the nonhedonic outcomes terminated equally often in food and no food. Thus, the correlation between correct sample-response sequence and hedonic outcome was zero in both groups.

Similar multidimensionally-different nonhedonic events have been shown to be effective differential outcomes in spatial discriminations with rats. In particular, Friedman and Carlson (1973) found enhanced acquisition if correct stimulus-response sequence (e.g., tone-left barpress, clicker-right barpress) was correlated with nonhedonic outcome (the presence *versus* the absence of light, that accompanied food reinforcement). Similarly, Fedorchak and Bolles (1986) found enhanced acquisition if correct sequence was correlated with outcome (the presence *versus* the absence of light, that accompanied water reinforcement). It was anticipated that multidimensionally-different nonhedonic

outcomes would also increase the robustness of nonhedonic DOEs in a DMTS task with pigeons.

To further enhance the effectiveness of the red and no-red events in the present experiment, 4 additional procedural modifications were introduced. First, to distinguish the nonhedonic outcomes even more, the red event, when it occurred, was presented simultaneously on all 3 keys, rather than just on the center key as had been the case in Experiment 1. Second, to further increase the likelihood that the nonhedonic outcomes would be noticed by subjects in group MDO, the DMTS task entailed a more difficult shape discrimination, using circle and triangle samples and test stimuli. It was anticipated that this modification would potentiate reliance upon expectancies in group MDO and, thereby, increase the difference between the MDO and NDO groups during acquisition, extended-delay testing, and transfer.

The third procedural modification was intended to provide a more powerful evaluation of transfer effects. Specifically, half of subjects in group MDO were tested in positive transfer, whereas remaining subjects in this group were given negative transfer testing. Thus, the predicted facilitative effect (positive transfer) of prior training with differential outcomes could be compared to a predicted disruptive effect (negative transfer) of such training, rather than to the null effect (neutral transfer) of prior training with nondifferential outcomes, as had been the case in Experiment 1. In other words, previous experience with the red and no-red differential outcomes should tend to produce accurate responding in the positive transfer condition, because presentation of a particular outcome, red or no red, as a transfer sample during testing, should tend to control choice of the specific test stimulus that, during training, had resulted in that particular event as

the outcome. For the same reason, such experience should tend to produce *inaccurate* responding in the negative transfer condition

To maintain comparability with group MDO, approximately half of subjects in group NDO was given testing identical to that in the positive transfer condition, whereas remaining NDO subjects were tested in the negative transfer condition. Note that previous experience with red and no-red nondifferential outcomes could not provide a basis for either positive or negative transfer in group NDO. Thus, regardless of transfer condition, presentation of a particular outcome, red or no red, as a transfer sample during testing, should tend to equally control choice of both test stimuli. This would occur because, during training, both correct sample-response sequences were equally likely to result in red and no-red outcomes. Thus, mediators of accurate responding in the positive transfer condition and inaccurate responding in the negative transfer condition should be absent in group NDO.

The fourth procedural modification involved use of a simpler transfer test. In Experiment 1, there was a concern that if the transfer procedure appeared excessively novel to the pigeons, performance in all 3 groups might undergo considerable disruption (generalization decrement) and, consequently, positive transfer in group CDO in the color transfer test and group HDO in the hedonic transfer test would be difficult to detect. To prevent this, the transfer procedure was designed to be as similar as possible to the baseline task (i.e., color and hedonic outcomes continued to follow correct choices in the transfer task).

In retrospect, however, this approach may still have introduced considerable disruption in transfer sessions for groups CDO and HDO. Recall that the color and

hedonic outcomes were presented nondifferentially to all subjects during both transfer sessions. Notice that this feature represented a procedural change from baseline conditions for groups CDO (for which the color outcomes had been presented differentially) and HDO (for which the hedonic outcomes had been presented differentially). This procedural novelty in transfer sessions might have obscured the magnitude of positive transfer in group CDO during the color transfer test and group HDO in the hedonic transfer test.

In Experiment 2, a much simpler transfer task was employed. Accordingly, in the transfer session, whereas the multidimensionally-different nonhedonic events replaced the samples used during baseline training, those events as outcomes were eliminated altogether. Instead, correct responses were always followed immediately by an hedonic outcome. Moreover, the hedonic outcome during transfer was always food, rather than equally often food and no-food, as had been the case during baseline training. It was believed that, despite the novelty of this transfer procedure, the task was relatively simple. As a result, it was anticipated that any disruption due to generalization decrement would be minimal, short-lived, and would not obscure manifest transfer effects.

Method

Subjects

The subjects were the same as those used in Experiment 1. Birds were maintained as described previously. Prior to Experiment 2, birds received some additional stages of training, and extended-delay and transfer testing, according to group conditions described in Experiment 1. However, results from these interim stages were not informative, and thus are not presented.

Birds were randomly assigned to 1 of 2 experimental groups, multidimensional differential outcomes (MDO) and nondifferential outcomes (NDO) with the restriction that, as closely as possible, present groups were equated for previous group membership. Thus, 3 former CDO subjects, 2 former HDO subjects, and 3 former NDO subjects were randomly assigned to group MDO ($n = 8$). Remaining birds (2 former CDO subjects, 3 former HDO subjects, and 2 former NDO subjects) were assigned to group NDO ($n = 7$).

Apparatus

The apparatus was the same as that used in Experiment 1, with the following exceptions. All 3 projectors were also equipped to transilluminate a white 1.0-cm ("large") circle and a white equilateral triangle (each side 1.0 cm in length), centered in the stimulus key on a black background. In addition, all projectors could transilluminate a homogeneous field of red.

Procedure

0-s DMTS Acquisition. Autoshaping prior to this phase of the experiment was not deemed necessary. Procedures and parameters of 0-s DMTS acquisition were exactly as in Experiment 1, with the following exceptions. The preparatory stimulus was a cross (accomplished by presenting the horizontal and vertical line orientations simultaneously on the center key) instead of a small circle, and all subjects were now required to accurately match the large circle and triangle shape stimuli (rather than horizontal and vertical line orientations) in an identity-matching task. In addition, correct choices produced a 3-s nonhedonic outcome, now either a red stimulus on all 3 keys (the "red" outcome) or no stimulus on any of the keys (the "no-red" outcome). As in Experiment 1, the nonhedonic outcome terminated in a 3-s illuminated hedonic event, equally often

food and no food.

Groups differed in terms of the correlations between correct choice and the nonhedonic outcome that followed. In group MDO, there was a perfect correlation between correct choice and nonhedonic outcome. For 4 subjects in this group, correct choice of the circle test stimulus always produced the red outcome and correct choice of the triangle test stimulus always produced the no-red outcome. For the remaining 4 subjects, these relations were reversed. In group NDO, there was a zero correlation between correct choice and nonhedonic outcome. Thus, correct choice of the circle test stimulus was as likely to be followed by a red as by a no-red outcome, and correct choice of triangle was also equally likely to produce red or no-red. Finally, for both groups, each nonhedonic outcome was as likely to terminate in food as in no food.

Performance within each session was evaluated by computing % correct choices over all trials. In addition to choices, number of keypeck responses to each of the 2 shape samples on the center key, and to each of the two nonhedonic outcomes on any of the 3 keys, were recorded, and rates of responding (keypecks per second) to samples and outcomes were computed. A minimum of 32 sessions of training was provided, and a group acquisition criterion was imposed. Zero-s DMTS acquisition was completed when group mean % correct was equal to or greater than 90% for 3 of 4 consecutive sessions (including sessions 29 to 32). After 48 sessions, in an effort to enhance acquisition in group NDO, the duration of the nonhedonic outcome was reduced from 3 to 1 s. After 60 sessions, in a further effort to enhance acquisition in this group, the probability of food (after the nonhedonic outcome) following correct sample-response sequences was increased from .5 to 1. Thereafter for group NDO, the duration of the nonhedonic

outcome was gradually increased, and the probability of food was gradually decreased: Respectively, to 1.5 s and p = .875 after session 68, to 2 s and p = .75 after session 72, to 2.5 s and p = .625 after session 76, and finally to the original values of 3 s and p = .5 after session 80.

Extended-Delay Testing. As each group met the acquisition criterion, it was immediately moved to extended-delay testing. Test sessions were identical to those of 0-s DMTS acquisition, with the following exceptions. Within each session, the 0-s delay of training occurred on only 75% of trials, whereas a 2-s delay occurred on 12.5% of trials and a 6-s delay occurred on 12.5% of trials. The three types of delay trials occurred randomly within sessions, with the restriction of equivalent numbers of circle and triangle sample presentations at each level of delay, counterbalanced for location of the correct test stimulus. As in Experiment 1, the correction procedure remained in effect, but if an incorrect choice occurred on an extended-delay trial, the correction trial replaced the extended delay with the 0-s training delay.

Extended-delay testing was conducted in 2 replications of 4 consecutive sessions. Performance was evaluated by computing % correct choices over all trials at each of the 3 delays. In addition, rates of responding to each of the 2 shape samples, and to each of the 2 nonhedonic outcomes, collapsed over the delay factor, continued to be computed. Four sessions of baseline training, identical to 0-s DMTS acquisition sessions, were interpolated between the 2 test replications. During baseline training, mean % correct in groups MDO and NDO were, respectively, 89.7 (range = 83.2 to 96.9) and 93.0 (range = 90.2 to 97.7).

Transfer Testing. Immediately prior to transfer testing, subjects were provided

with 16 consecutive sessions of baseline training, identical to 0-s DMTS acquisition sessions. Over the final 4 sessions of baseline training, mean % correct in groups MDO and NDO were, respectively, 91.1 (range = 86.7 to 96.5) and 92.2 (range = 90.2 to 96.9).

All subjects in both groups received a single transfer session, which was identical to a session of 0-s DMTS acquisition with the following exceptions. Rather than circle and triangle shape samples, either the 3-key red outcome or the no-red outcome was presented for 3 s as a transfer sample on each trial. Note that the duration of the nonhedonic event as a transfer sample was equivalent to its duration when as an outcome during training. This was done to enhance the likelihood that the transfer samples would be perceived as the same events as the previously experienced nonhedonic outcomes.

Transfer sample offset was followed immediately by presentation of the circle and triangle stimuli on the side keys for a choice response. In the positive transfer conditions of both groups MDO and NDO, correct (and incorrect) choices were defined so as to be consistent with the associations between correct choices and nonhedonic outcomes that had been experienced by group MDO during baseline training. For instance, if, during training, a correct circle choice resulted in the red outcome and a correct triangle choice resulted in the no-red outcome, then, during testing, a circle choice was considered correct (and a triangle choice was considered incorrect) after a red transfer sample and triangle choice was considered correct (and a circle choice was considered incorrect) after a no-red transfer sample.

Alternatively, in the negative transfer conditions of both groups MDO and NDO, correct (and incorrect) choices were defined so as to be *inconsistent* with the associations between correct choices and nonhedonic outcomes that had been experienced by group

MDO during baseline training. For instance, if, during training, a correct circle choice resulted in the red outcome and a correct triangle choice resulted in the no-red outcome, then, during testing, a triangle choice was considered correct (and a circle choice was considered incorrect) after a red transfer sample and circle choice was considered correct (and a triangle choice was considered incorrect) after a no-red transfer sample. Note that designations of positive and negative transfer are completely arbitrary for group NDO, as these subjects had received the outcomes nondifferentially during training.

Four subjects from group MDO and 3 subjects from group NDO were randomly assigned to the positive transfer condition, and remaining subjects (4 from each of groups MDO and NDO) were assigned to the negative transfer condition. For group MDO subjects, assignment to transfer conditions was counterbalanced with respect to the associations between specific shape samples and nonhedonic outcomes that had been experienced during training. Thus, for each transfer condition, 2 MDO birds had originally received the red outcome after correct circle choices and the no-red outcome after correct triangle choices, whereas the remaining 2 MDO birds had originally received the no-red outcome after correct circle choices and the red outcome after correct triangle choices.

During the transfer session, all correct choices resulted immediately in 3-s presentation of illuminated food (i.e., the red and no-red events were no longer presented as outcomes), followed by the 15-s ITI. All incorrect choices resulted in a 3-s timeout, followed by the ITI, and then a repeat of the trial in which the incorrect choice occurred (i.e., the correction procedure remained in effect). As before, responses on correction trials were not recorded, but correct choices on such trials resulted in presentation of

food, as on noncorrection trials. Trials during the transfer session were blocked into 4 consecutive blocks of 16 trials per block. Each block consisted of 4 presentations of each of the 4 possible trial types (2 transfer samples x 2 left/right locations of the shape test stimuli), presented in random order.

Performance within each block of the transfer session was evaluated by computing % correct choices over all trials of that block. In addition to choices, rates of responding to the red and no-red samples on any of the 3 keys, collapsed over blocks of trials within the transfer session, were computed.

Results and Discussion

0-s DMTS Acquisition. Acquisition proceeded much more quickly in group MDO than in group NDO. For each subject, number of sessions required before at least 80% correct occurred for the first time in a session was determined. Two subjects in group NDO failed to meet this acquisition criterion within the first 48 sessions of training (i.e., before extraordinary training procedures were instituted) and, hence, were given a score of 48 sessions. Mean sessions required to meet criterion was 9.8 (range = 3 to 23) in group MDO and 25.0 (range = 8 to 48) in group NDO. A one-way ANOVA on these data returned a significant effect for group, $F(1,13) = 5.19$, confirming that learning occurred more quickly in group MDO than in group NDO.

Similarly, accuracy across blocks of sessions (4 sessions per block) also indicated that learning was much faster in group MDO than in group NDO. Figure 4 shows rates of acquisition in the 2 groups over the first 32 sessions of training (collapsed into 4-session blocks), the only sessions from which there were data for all subjects. A split-plot ANOVA on these data returned significant main effects for group, $F(1,13) = 9.67$,

and block, $F(7,91) = 32.25$. Most important, a significant Group x Block interaction, $F(7,91) = 2.79$, again confirmed that learning was more rapid in group MDO than in group NDO.

It should be noted that acquisition of the shape-matching task in the present experiment appeared to proceed more slowly than acquisition of the line-matching task in Experiment 1, especially for group NDO subjects. This occurred despite use in Experiment 2 of experienced animals, a less-stringent acquisition criterion, and facilitative training procedures after session 48 (i.e., shorter durations of nonhedonic outcomes, increased probabilities of food reinforcement). This observation confirms the anticipation, stated in the introduction to this experiment, that birds should find the shape-matching task more difficult and, consequently, subjects in group MDO might be more likely to rely upon expectancies of the multidimensionally-different nonhedonic outcomes.

Accuracy in the final 4 sessions of training for each group was almost identical. Over sessions 29 to 32, mean % correct in group MDO was 90.7 (range = 84.8 to 96.9) and over sessions 87 to 90, mean % correct in group NDO was 90.3 (range = 79.7 to 96.1). A one-way ANOVA failed to show a significant effect for group, thereby indicating that asymptotic accuracy was statistically equivalent in the two groups.

An SDR was computed over each subject's final 4 sessions of training. Additionally and in similar fashion, an outcome discrimination ratio (ODR) was also computed, as an index of the degree to which differential responding had developed to the nonhedonic outcomes. For each subject's final block of acquisition, the response rate on the nonhedonic outcome to which responding was most rapid was divided by the sum

of the response rates on each of the 2 outcomes. Hence, as with the SDR, an ODR of .5 indicates nondifferential responding to the outcomes (i.e., equivalent rates of responding to the red and no-red outcomes), and an ODR approaching the limit (1.0) indicates increasingly differential outcome response rates.

Not surprisingly, both groups demonstrated very high ODRs, responding much more rapidly to the red outcome than to the no-red outcome. This pattern prevailed in all subjects in both groups. Mean ODR was slightly lower in group MDO (M = .96, range = .81 to 1.00) than in group NDO (M = 1.00, no variance), but this difference was not significant in a one-way ANOVA.

Perhaps somewhat more surprising was a slight group difference in SDR, which was modestly higher in group MDO (M = .73, range = .52 to 1.00) than in group NDO (M = .65, range = .52 to .82), although this difference was not significant in a one-way ANOVA. The sample to which responding was most rapid was the red-associated shape for 6 of 8 subjects in group MDO, and the circle shape for 5 of 7 subjects in group NDO. The remaining subjects in each group responded more rapidly to the alternate sample.

In general, results provide considerable evidence in support of an expectancy account of the nonhedonic DOE during 0-s DMTS acquisition, in that there were significant trends toward faster learning in group MDO than in group NDO, and the magnitude of differential sample responding was equivalent in both groups. These findings suggest that expectancies of the multidimensionally-different nonhedonic events facilitated learning of the DMTS task.

Accordingly, due to the perfect correlation between correct sample-response sequence and nonhedonic outcome in group MDO, each of the two shape samples came

to activate a unique expectancy, each consisting of a representation of the nonhedonic outcome with which that sample was associated. These salient differential outcome expectancies provided a discriminative basis for correct test stimulus choices, in addition to that provided by the circle and triangle stimuli themselves. By contrast, due to the zero correlation between correct sample-response sequence and outcome in group NDO, the two shape samples came to activate the same red/no-red outcome expectancy. Thus, expectancies could not provide an additional basis for correct test stimulus responding, and subjects had to rely entirely on the less discriminable shape stimuli.

Analysis of SDR data are inconsistent with a behavioral-mediation account of the present nonhedonic DOE in acquisition. Although differential sample responding was observed in group MDO, the magnitude of such responding did not differ statistically from that observed in group NDO. Presumably then, any distinct and discriminable proprioceptive stimuli that resulted from differential sample responding, and that may have facilitated 0-s DMTS acquisition, were equally available to subjects in both groups. Hence, the difference in rate of learning likely resulted from salient and highly differential outcome expectancies that were available in group MDO, but not in group NDO.

Extended-Delay Testing. Patterns in retention were similar in both replications of extended-delay testing. Figure 5, upper and lower panels, show percent correct as a function of increasing delay for the first and second replications, respectively. In both replications, retention appeared to be stronger in group MDO than in group NDO, in that accuracy declined less rapidly with increasing delay in the former group. The difference in retention appeared to be more pronounced at the 2-s delay, but dissipated somewhat at

the 6-s delay, especially in the first replication.

A split-plot ANOVA was conducted on extended-delay test data. Although the replication main effect was significant, $F(1,13) = 7.82$, indicating higher accuracy in the second replication, this term did not interact with any other factor. The main effect for delay was also significant, $F(2,26) = 105.25$. But most important, the Group x Delay interaction was significant, $F(2,26) = 3.98$, indicating stronger retention in group MDO than in group NDO. This interaction term was further explored with multiple comparisons, which showed the absence of group differences in accuracy at the 0- and 6-s delays, with higher accuracy in group MDO than group NDO at the 2-s delay.

Mean group SDRs and ODRs, collapsed over replication, were computed. As during acquisition, mean SDR was slightly higher in group MDO ($M = .74$, range = .52 to .93) than in group NDO ($M = .69$, range = .51 to .88), but this difference was not significant in a one-way ANOVA. The sample to which responding was most rapid was the red-associated sample for 6 of 8 subjects in group MDO, and the circle sample for 5 of 7 subjects in group NDO. The remaining subjects in each group responded more rapidly to the alternate sample. Also as during acquisition, all subjects in both groups responded more rapidly to the red outcome than to the no-red outcome. And although mean ODR was slightly higher in group MDO ($M = .98$, range = .93 to 1.00) than in group NDO ($M = .89$, range = .54 to 1.00), this difference was not significant in a one-way ANOVA.

Overall, the availability of multidimensionally-different nonhedonic outcomes facilitated retention in group MDO compared to group NDO, especially at the 2-s delay. However, by the 6-s delay the advantage in retention had dissipated and was no longer

significant. Still, extended-delay testing provided at least some evidence consistent with an expectancy account of the nonhedonic DOE on working memory performance. Evidently, however, although the availability of differential outcome expectancies facilitates retention, facilitation seems to dissipate with increasing delays.

Corroborating evidence for use of expectancies in group MDO was the finding that groups demonstrated similar magnitudes of differential sample responding. Presumably then, groups did not differ with respect to which distinct and discriminable proprioceptive stimuli were available during extended-delay testing. Hence, the difference in retention likely resulted from use of differential expectancies of the nonhedonic outcomes that were available to subjects in group MDO but not in group NDO.

Transfer Testing. In the single transfer session for group MDO, total % correct was considerably greater in the positive than in the negative transfer condition, and block % correct was greater in later than in earlier trial blocks. Most important, across trial blocks, accuracy in the positive transfer condition tended to increase, whereas accuracy in the negative transfer condition tended to decrease (Figure 6, upper panel). These trends suggest facilitation of matching accuracy in the positive transfer group, and suppression of matching accuracy in the negative transfer group. And although a split-plot ANOVA on % correct failed to return reliable condition or block main effects, the Condition x Block interaction was significant, $F(3,18) = 3.51$. Multiple comparisons indicated greater % correct in the positive than in the negative transfer condition during trial blocks 3 and 4, whereas between-condition differences during trial blocks 1 and 2 were not significant.

In the single transfer session for group NDO, by comparison, total % correct was

slightly greater in the positive than in the negative transfer condition, and block % correct was considerably greater in later than in earlier trial blocks. However, a split-plot ANOVA on % correct failed to return significant main effects for either block or condition. Most important, across trial blocks, accuracy in both the positive and negative transfer condition tended to increase with no apparent systematic differences between the two conditions (Figure 6, lower panel). These trends suggest equivalent improvement of matching accuracy over blocks in both the positive and negative transfer groups. The ANOVA confirmed this impression, in that the Condition x Block term was not statistically significant.

It is possible that group differences in transfer testing could be explained in terms of behavioral mediation, on the basis of transfer of differential responding to the red and no-red transfer samples. Consider that just prior to the transfer test, almost all subjects demonstrated differential patterns of responding to the red and no-red outcomes. For subjects in group MDO, these differential response patterns tended to transfer to their shape-sample associates, presumably because of the correlation between correct sample-response sequence and outcome. Specifically, in sessions just prior to the transfer test, subjects in this group tended to peck the red-associated shape sample more frequently than the no-red-associated shape sample. Consequently, differential patterns of sample responding could have gained some control over correct choice of the shape test stimuli. Next, during transfer testing, all subjects responded much more frequently to the red transfer sample than to the no-red transfer sample. Therefore, for group MDO, these differential patterns of responding to the transfer samples could have mediated positive and negative transfer. Note that this behavioral process could not have operated in group

NDO, due to the zero correlation between correct sample-response sequence and outcome during training. Consequently, differential patterns of responding to the nonhedonic outcomes could not have transferred to the shape samples during training and, as a result, differential patterns of responding to the transfer samples could not have mediated positive and negative transfer during testing.

This behavioral-mediation account predicts that, in group MDO, the tendency to respond to the red-associated shape sample prior to the transfer test should be positively related to the tendency to respond to the red transfer sample during the transfer test. To test this prediction, two discrimination ratios were determined for each subject in group MDO, one by computing the ratio of red-associate shape responses to total sample responses during the final 4 sessions of training prior to the transfer session, and a second by computing the ratio of red responses to total transfer sample responses during the single transfer session. The Pearson product-moment correlation coefficient between these two ratios was moderately positive, .23, but did not differ significantly from zero in a *t*-test. Therefore, the transfer effect in group MDO cannot be explained in terms of transfer of differential rates of sample responding.

Thus, results of the transfer test provided strong evidence for expectancy theory, in that group MDO showed a robust transfer effect whereas group NDO demonstrated no evidence of transfer, and the transfer effect in group MDO could not be attributed to control by differential rates of sample responding. These findings indicate that expectancies of multidimensionally-different nonhedonic outcomes can subsequently mediate performance in a novel DMTS task that presents those nonhedonic events as transfer samples. Specifically for group MDO, presentation of a particular outcome, red

or no red, as a transfer sample during testing, tended to control choice of the specific shape test stimulus that, during training, had resulted in that particular nonhedonic event as the outcome. Presumably, such control was mediated by expectancies of the nonhedonic outcomes that corresponded to the transfer samples themselves. This process tended to facilitate accurate responding in the positive transfer condition, and suppress accurate responding (indeed, promote *in*accurate responding) in the negative transfer condition. By comparison for group NDO, presentation of a particular outcome, red or no red, as a transfer sample during testing, tended to control choice of both shape test stimuli because, during training, both nonhedonic events were equally likely as the outcome following correct choice of either shape test stimulus. Consequently, during the transfer session, control of choice responding could not be mediated by outcome expectancies. Thus, neither facilitation of accurate responding in the positive transfer condition, nor promotion of inaccurate responding in the negative transfer condition, could occur.

Overall, results of the present experiment provide strong support for expectancy theory. Nonhedonic DOEs were observed in acquisition, extended-delay testing, and transfer testing, and such effects could not be attributed to a behavioral process based on differential sample responding. Evidently, nonhedonic outcome expectancies of red and no-red in the present experiment provided a cue that was considerably more discriminable and memorable than the sensory features of circle and triangle shape stimuli alone. Additionally, such expectancies provided strong mediators of transfer to a novel procedure in which those nonhedonic events were presented as samples. Finally, consider the reliable differences between groups MDO and NDO throughout the present

experiment, compared to the inconsistent differences between comparable groups (i.e., groups CDO and NDO) throughout Experiment 1. Notwithstanding the procedural differences between the two experiments, this consideration suggests that differential outcome expectancies derived from multidimensionally-different red and no-red outcomes (group MDO, present experiment), are more discriminable, memorable, and transferable, than differential outcome expectancies derived from unidimensionally-different red and green outcomes (group CDO, Exp. 1).

Experiment 3

Experiment 1 demonstrated hedonic DOEs with food and no-food outcomes, in that group HDO generally outperformed groups CDO and NDO, especially during extended-delay and hedonic transfer testing. However, hedonic DOEs could easily be attributed to a behavioral-mediation process based on differential sample responding. Moreover, there was little evidence of nonhedonic DOEs with red and green outcomes, in that performance in groups CDO and NDO was very similar throughout all phases of that experiment. In contrast, Experiment 2 showed robust nonhedonic DOEs with multidimensionally-different red and no-red outcomes, in that group MDO outperformed group NDO during acquisition and extended-delay testing. Additionally, a reliable transfer effect was present in the former but not the latter group. Importantly, throughout Experiment 2 nonhedonic DOEs could not be attributed to a behavioral-mediation process based on differential sample responding, and a central expectancy process was implicated instead.

Taken together, these results suggest that use of expectancies by pigeons in the present DMTS task requires use of multidimensionally-different outcome events, at least

when nonhedonic outcomes are employed. On this view, unidimensionally-different nonhedonic outcomes like red and green may yield expectancies that are difficult for pigeons to differentiate. Note that red and green outcomes differ primarily along a single stimulus dimension, visual wavelength. Thus, perhaps effective nonhedonic outcomes must consist of multidimensionally-different events that, consequently, result in expectancies that are easily differentiated by pigeons.

Alternatively, it is possible that nonhedonic DOEs occurred in the second but not the first experiment merely because Experiment 2 introduced a number of procedural modifications that may have, by themselves, resulted in easier-to-differentiate expectancies. In other words, perhaps some combination of the 3-key outcome presentation, the difficult shape discrimination, the more powerful evaluation of transfer, and the simpler transfer procedure, enhanced the distinctiveness of the nonhedonic outcomes and/or made expectancies more detectable. Thus, perhaps use of multidimensionally-different events *per se*, was not critical for presence of nonhedonic DOEs in Experiment 2, and absence of such effects in Experiment 1.

As a third alternative, it is possible that nonhedonic DOEs occurred in the second but not the first experiment because, contrary to the intuition that the red and no-red events of Experiment 2 comprised nonhedonic outcomes, these events may have in fact differed along the hedonic dimension after all. Note that the DMTS task with nonhedonic outcomes also contains the operations by which to establish conditioned (secondary) reinforcers. Specifically, for all subjects, both the red outcome and the no-red outcome were frequently followed by unconditioned (primary) reinforcement, i.e., food. Accordingly, both red and no-red outcomes should have become secondary

reinforcers. However, on the finding that an "explicit" secondary reinforcer (e.g., the presence of a discrete stimulus) is a more effective mediator of a delay to primary reinforcement, compared to an "implicit" secondary reinforcer (e.g., the absence of any discrete stimuli) (e.g., Williams, 1994), it is likely that the red event became a more effective secondary reinforcer than the no-red event in Experiment 2. If so, then it is reasonable to assume that birds may have also developed an hedonic preference for the red outcome over the no-red outcome. Thus, on this secondary reinforcement interpretation, red and no-red may have manifested as hedonic outcomes as training proceeded in Experiment 2.

Note that in group MDO, one correct sample-response sequence always resulted in the more preferred secondary reinforcer (i.e., the red outcome), whereas the second correct sequence always resulted in the less preferred secondary reinforcer (i.e., the no-red outcome). And indeed, there appeared to be a tendency for birds in this group to express their preferences behaviorally, by responding more rapidly to the red-associated sample than to the no-red-associated sample. Thus, the secondary reinforcement view posits that differential sample responding could have provided salient response-controlling proprioceptive cues to group MDO subjects, which would not have been available to subjects in group NDO. Recall that for group NDO, both secondary reinforcers occurred equally often after both types of correct sample-response sequences. Hence, for these birds, a preference for the red over the no-red outcome could not be expressed in differential-sample responding, because both samples were equally associated with both outcomes.

Although the tendency to demonstrate differential sample responding was

modestly higher in group MDO that in group NDO, ultimately the difference was not statistically significant. It should also be noted that hedonic DOEs in pigeons are typically characterized by higher accuracy on trials in which the more favored hedonic outcome is forthcoming, compared to trials in which the less favored hedonic outcome is forthcoming. For example in Experiment 1, group HDO responded more accurately on trials in which the food-associated sample was presented than trials in which the no-food-associated sample was presented, respectively, 98.7% and 90.0% in the final session of 0-s DMTS acquisition. By contrast in Experiment 2, group MDO responded *less* accurately on trials in which the red-associated sample was presented than on trials in which the no-red associated sample was presented, respectively, 88.7% and 91.0% in the final session of 0-s DMTS acquisition. Thus, if accuracy is an indication of hedonic value of the outcome, then these data also fail to show that the red event was hedonically more favorable than the no-red event. Nevertheless, the secondary reinforcement account of DOEs in Experiment 2 is plausible and merits further investigation.

Experiment 3 was designed to explore the source of the DOEs obtained in Experiment 2. To do so, the no-red outcome was simply replaced by a 3-key green outcome (see Table 4). Hence, the multidimensionally-different nonhedonic outcomes (i.e., red and no red) of Experiment 2 were rendered unidimensionally-different nonhedonic outcomes (i.e., red and green), and an explicit secondary reinforcer (i.e., either red or green) was presented after all correct sample-response sequences. In addition, subjects previously in group MDO experienced *unidimensional differential outcomes* (UDO), in which the specific shape-red outcome association of Experiment 2 was retained. Consequently, the particular shape that was associated with the no-red

outcome in the previous experiment was associated with the green outcome in the present experiment. Finally, group NDO birds of Experiment 2 continued to receive nondifferential outcomes in the present experiment, except that now the 3-key green outcome occurred in lieu of the no-red outcome.

If the DOEs of Experiment 2 were the result of (1) use of multidimensionally-different nonhedonic outcomes, and unidimensionally-different nonhedonic outcomes cannot support such effects, and/or (2) a secondary-reinforcement mechanism that produced hedonic differences between the red and no-red outcomes, then DOEs should be eliminated in the present experiment. Alternatively, if the DOEs of the previous experiment were attributable to one or more of the four procedural modifications introduced in Experiment 2, which merely enhanced the differentiation between the nonhedonic outcome expectancies, then such effects should persist in Experiment 3.

Method

Subjects

The subjects were the same as those used in Experiments 1 and 2, and birds were maintained as described previously. All 8 subjects from group MDO in Experiment 2 were assigned to group unidimensional differential outcomes (UDO), whereas all 7 subjects from group NDO in Experiment 2 remained in group NDO.

Apparatus

The apparatus was the same as that used in Experiment 2, except that all 3 projectors were now also equipped to transilluminate a homogeneous field of green.

Procedure

0-s DMTS Acquisition. Procedures and parameters of 0-s DMTS acquisition were

identical to Experiment 2, with a single exception: The no-red outcome was replaced by a 3-s green stimulus on all 3 keys (the "green" outcome). Thus, the former multidimensionally-different nonhedonic outcomes (red and no red) now comprised unidimensionally-different nonhedonic outcomes (red and green) for both groups.

Groups continued to differ in terms of the correlations between correct choice and the outcome that followed. Specifically, group UDO continued to experience a perfect correlation between correct sample-response sequence and outcome (Table 4, upper panel; cf., group CDO in Table 2, middle panel), whereas group NDO continued to receive a zero correlation between correct sequence and outcome (Table 4, lower panel; cf., group NDO in Table 2, lower panel). In addition, for each subject in group UDO, the relationship between the particular shape stimulus and red outcome that prevailed in Experiment 2 was maintained in Experiment 3. Consequently, for each subject in group UDO, the particular shape stimulus that was associated with the no-red outcome in Experiment 2 was now associated with the green outcome in Experiment 3. Finally, as before, each of the two outcomes were equally likely to terminate in food or no food for both groups.

Acquisition performance was evaluated as in Experiment 2, except that accuracy was additionally separated with respect to trial type in group UDO (% correct on red- and green-associated trial types) for reasons to be given in the Results and Discussion section. Number of keypeck responses to each of the 2 shape samples on the center key, and to each of the 2 nonhedonic outcomes on any of the 3 keys, were also recorded, and rates of responding (keypecks per second) to samples and outcomes were computed. Ten sessions of training were given, after which acquisition was considered to be complete.

In the final session of acquisition, mean % correct in groups UDO and NDO were, respectively, 91.2 and 91.5 (range = 84.4 to 98.4 in both groups).

Extended-Delay Testing. As each group met the acquisition criterion, it was moved immediately to extended-delay testing. This test was conducted exactly as in Experiment 2, with a single exception: The no-red outcome was replaced by the 3-key green outcome.

Extended-delay testing was conducted in 2 replications of 4 consecutive sessions, with 4 sessions of baseline training, identical to 0-s DMTS acquisition, interpolated between the 2 test replications. Performance was evaluated as in Experiment 2, and rates of responding to each of the two shape samples, and to each of the two nonhedonic outcomes on any of the 3 keys, continued to be computed. Over the 4 sessions of interpolated baseline training, mean % correct in groups UDO and NDO were, respectively, 92.7 (range = 87.5 to 96.9) and 92.7 (range = 86.3 to 97.7).

Transfer Testing. Immediately prior to transfer testing, subjects were provided with 16 consecutive sessions of baseline training, identical to 0-s DMTS acquisition. Over the final 4 sessions of baseline training, mean % correct in groups UDO and NDO were, respectively, 92.9 (range = 85.9 to 97.3) and 93.3 (range = 87.9 to 99.2).

Next, subjects received 4 consecutive transfer sessions, each of which were identical to the single transfer session in Experiment 2 in all respects except for three. First, the 3-key green event replaced the no-red transfer sample. Second, the duration of the transfer samples was increased from 3 to 5 s, to enhance the likelihood that subjects would completely process the transfer samples. Third, within both groups, 2 randomly chosen subjects that had served in the positive transfer condition of Experiment 2, and 2

randomly chosen subjects that had served in the negative transfer condition of Experiment 2, were given negative transfer testing in Experiment 3. The remaining 4 subjects in group MDO and 3 subjects in group NDO were given positive transfer testing in Experiment 3. This assignment was undertaken to equate positive and negative transfer conditions of Experiment 3, both within and between groups UDO and NDO, for any learning about the association between the red transfer sample and the correct shape test stimulus that might have occurred as a result of the single session of transfer in Experiment 2.

As before, in the positive transfer condition of both groups UDO and NDO, correct (and incorrect) choices were defined so as to be consistent with the associations between correct choices and nonhedonic outcomes during baseline training for group UDO. For instance, if, during training, a correct circle choice resulted in the red outcome and a correct triangle choice resulted in the green outcome, then, during testing, a circle choice was considered correct (and a triangle choice was considered incorrect) after a red transfer sample and a triangle choice was considered correct (and a circle choice was considered incorrect) after a green transfer sample.

Conversely, in the negative transfer condition of both groups UDO and NDO, correct (and incorrect) choices were defined so as to be inconsistent with the associations between correct choices and nonhedonic outcomes during baseline training for group UDO. For instance, if, during training, a correct circle choice resulted in the red outcome and a correct triangle choice resulted in the green outcome, then, during testing, a triangle choice was considered correct (and a circle choice was considered incorrect) after a red transfer sample and a circle choice was considered correct (and a triangle choice was

considered incorrect) after a green transfer sample. Note that, as in Experiment 2, designations of positive and negative transfer were completely arbitrary for group NDO, as these subjects would have received the outcomes nondifferentially during training.

Performance within each of the 4 transfer sessions was evaluated as in Experiment 2 (i.e., 4 consecutive 16-trial blocks per session), and rates of responding to the red and green test samples on any of the 3 keys (collapsed over blocks of trials within each transfer session) continued to be computed.

Results and Discussion

0-s DMTS Acquisition. The left-most symbols in the upper panel of Figure 7 display % correct the 2 groups over the final 4 sessions of 0-s DMTS baseline training with multidimensionally-different (red and no-red) outcomes (just prior to transfer testing in Experiment 2). Symbols to the right display % correct over the 10 sessions of acquisition with unidimensionally-different (red and green) outcomes in Experiment 3. This figure shows very little disruption in baseline performance in group NDO, in that accuracy remained high and stable throughout acquisition. By contrast, there was considerable disruption over initial sessions in group UDO, in that accuracy dropped below that recorded during previous baseline training. This disruption gradually dissipated as acquisition proceeded. A split-plot ANOVA was conducted on data from the 10 sessions of acquisition, with group as a between-subjects factor, and session as a within-subjects factors. This analysis returned a significant main effect for sessions, $F(9,117) = 3.14$, indicating lower accuracy in earlier than later sessions. In addition, the Sessions x Group interaction was significant, $F(9,117) = 2.64$, indicating that initial disruption in accuracy was more marked in group UDO.

The lower panel of Figure 7 shows that the deterioration during early sessions of acquisition in group UDO was greater on green-associated (previously no-red-associated) sample trials than on red-associated sample trials. Interestingly, this observation is consistent with the expectancy account of nonhedonic DOEs in Experiment 2. Consider that during the previous experiment, subjects in the present group UDO presumably had learned to expect red and no-red outcomes, because of the correlation between correct sample-response sequence and outcome. Consequently at the outset of the present experiment, on trials in which the formerly no-red-associated (currently green-associated) sample had been presented, the no-red outcome would be expected. However, on such trials (assuming that the subject chose the correct test stimulus), the "unexpected" green outcome would have been presented instead. As a result, some disruption in accuracy would be anticipated on these trials. Moreover, less disruption should be observed on trials in which the red-associated sample was presented. After all, in the present experiment, the red outcome continued to occur as expected. Ultimately however, this differential disruption with respect to trial type in group UDO was not statistically significant. A repeated-measures ANOVA with sessions and trial type as within-subjects factors returned only a significant session effect, $F(9,63) = 5.16$.

By comparison to group UDO, subjects in the present group NDO should not have learned, during Experiment 2, to expect the multidimensional outcomes. Indeed, these subjects might have even learned to ignore the red and no-red events, due to the zero correlation between correct sample-response sequence and outcome. Consequently, very little disruption would be anticipated when the green outcome was substituted for the no-red outcome. This prediction was supported by acquisition data.

However, it is possible that a behavioral process, similar to that described in the *Results and Discussion* of transfer testing in Experiment 2, might be responsible for the disruption in group UDO. Specifically, by the end of Experiment 2, all subjects tended to respond more rapidly to the red outcome than to the no-red outcome. In the previous group MDO (i.e., the present group UDO), differential rates of responding to the outcomes tended to transfer to their sample associates, presumably because of the correlation between sample-response sequence and outcome. As a result, subjects in this group tended to respond more rapidly to the red-associated shape sample than to the no-red-associated shape sample. Consequently, differential rates of sample responding might have gained some control over test stimulus choice. Next, when the green outcome was introduced in the present experiment, rate of responding to the green (formerly no-red) outcome might have increased and, as a result, rate of responding to the green-associated (formerly no-red-associated) shape sample might also have increased. In this way, the functional controlling stimulus, differential rates of sample responding, would have been lost and choice accuracy would have declined as a result.

This behavioral-mediation account predicts that, in group UDO, the tendency to respond more rapidly to the red-associated shape sample should have decreased at the outset of acquisition in the present experiment, when compared to the tendency to respond more rapidly to the red-associated sample at the end of Experiment 2. To test this prediction, two discrimination ratios were determined by computing the ratio of red-associate shape responses to total sample responses, the first over the final 4 sessions of baseline training (just prior to the transfer test) in Experiment 2, and the second in the initial session of acquisition in the present experiment. These discrimination ratios

turned out to be remarkably similar. Over the final 4 sessions of baseline training and in the initial session of acquisition, mean discrimination ratios were, respectively, .67 (range = .22 to .95) and .70 (range = .27 to 1.00) for group UDO. A repeated-measures ANOVA indicated no difference in tendency to respond more rapidly to the red-associate shape sample over the two conditions. Evidently, introduction of the green outcome had little or no effect on the extent of the tendency to respond more rapidly to the red-associated shape sample in group UDO. Hence, disruption during initial sessions of acquisition in group UDO cannot be attributed to a behavioral mediation process based on disrupted patterns of differential sample responding.

Overall, results of acquisition support the interpretation of performance in group MDO in the previous experiment, as reflecting use of expectancies of the multidimensionally-different nonhedonic outcomes, at least in part, as the basis for test stimulus choice. Otherwise, disruption in initial sessions of acquisition in the present experiment, with a tendency for greater disruption on trials with the green-associated sample, should not have occurred. Still, by the end of acquisition, accurate responding was observed in both groups. Presumably as training proceeded, subjects in group UDO either (1) learned to correctly expect the green outcome (i.e., if pigeons are able to form expectancies of unidimensionally-different nonhedonic outcomes), or (2) learned to choose between test stimuli solely on the basis of the shape samples (i.e., if pigeons are unable to form expectancies of unidimensionally-different nonhedonic outcomes).

Extended-Delay Testing. Figure 8, upper and lower panels, displays % correct as a function of increasing delay for the first and second replications, respectively. Retention appeared to be stronger in group UDO than in group NDO, in that accuracy

declined less rapidly with increasing delay in the former group. The difference in retention appeared to be more pronounced in the second replication.

A split-plot ANOVA was conducted on extended-delay test data, and returned a significant main effect for group, $F(1,13) = 6.59$, indicating higher overall accuracy in group UDO than in group NDO. The main effect of delay was also significant, $F(2,26) = 161.22$, indicating higher accuracy at shorter than at longer delays. However, all other terms were not significant, including the most important Group x Delay interaction. Thus, despite the visual impression contained in Figure 8, especially in the lower panel, retention during extended-delay testing was equivalent in the two groups.

Mean group SDRs, collapsed over replications, were computed. Mean SDR was slightly higher in group UDO ($M = .74$, range = .52 to .93) than in group NDO ($M = .69$, range = .51 to .88), but this difference was not significant in a one-way ANOVA. The sample to which responding was most rapid was the red-associated sample for 6 of 8 subjects in group UDO, and the circle sample for 3 of 7 subjects in group NDO. The remaining subjects in each group responded more rapidly to the alternate sample.

Generally, subjects in both groups responded at roughly equal rates to the red and green outcomes. Mean ODR was .59 in group UDO (range = .51 to .75) and .54 in group NDO (range = .50 to .60), but this slight difference was not significant in a one-way ANOVA. The red outcome was responded to more rapidly by 4 of 8 subjects in group UDO and by 1 of 7 subjects in group NDO. The remaining subjects responded more rapidly to the green outcome.

In general, the availability of differential red and green outcomes failed to facilitate retention in group UDO, compared to group NDO. However, trends in the data

were in the predicted direction, as group UDO appeared to show stronger accuracy with extended delays, especially in the second replication. Thus, there is at least some indication that pigeons can form expectancies of unidimensionally-different nonhedonic outcomes, and then store those expectancies in working memory to mediate an extended delay.

Support for use of expectancies of the nonhedonic outcomes in group UDO was the finding that groups demonstrated similar magnitudes of differential sample responding. Presumably then, groups did not differ with respect to which distinct and discriminable proprioceptive stimuli were available during extended-delay testing.

Transfer Testing. Figure 9 displays % correct as a function of transfer trial block (1 to 16) and session (1 to 4) in the positive and negative transfer conditions of group UDO (upper panel) and group NDO (lower panel). There was considerable variability in accuracy over transfer trial blocks. Hence, the following analyses used accuracy over transfer sessions, which demonstrated the same general pattern but showed much less variability. In the 4 transfer sessions for group UDO, % correct was greater in later than in earlier sessions, and total % correct was greater in the positive than in the negative transfer condition. Most important, across transfer sessions, accuracy tended to increase more quickly in the positive than in the negative transfer condition, suggesting facilitation of matching accuracy in the positive transfer group, and suppression of matching accuracy in the negative transfer group. Although a split-plot ANOVA on % correct failed to return reliable session or condition main effects, the Condition x Session interaction was significant, $F(3,18) = 3.36$. Multiple comparisons indicated greater % correct in the positive than in the negative transfer condition during sessions 2 and 3,

whereas between-condition differences during sessions 1 and 4 were not significant.

In the 4 transfer sessions for group NDO, by comparison, session % correct was considerably greater in later than in earlier sessions, but was virtually identical over sessions in the positive and negative transfer conditions. A split-plot ANOVA confirmed these impressions, with nonsignificant terms for condition and Condition x Session. The effect for session was significant, $F(3,15) = 12.09$, indicating higher accuracy in later than in earlier transfer sessions.

As in Experiment 2, it is possible that group differences in the transfer test could be explained in terms of behavioral mediation, on the basis of differential sample responding. Consider if group UDO demonstrated differential patterns of responding to the red and green outcomes just before the transfer test and, as a result, corresponding patterns of differential responding to the red-associated and green-associated shape samples had emerged. Thus, differential patterns of sample responding could have gained some control over correct choice of the shape test stimuli. Subsequently, during transfer testing, patterns of differential responding to the color transfer stimuli could have mediated positive and negative transfer in group UDO. Again, this behavioral process could not have operated in group NDO, due to the zero correlation between correct sample-response sequence and outcome during training.

As before, this behavioral-mediation account predicts that group UDO should show a strong correlation between the tendency to respond to the red-associated shape sample prior to the transfer test and the tendency to respond to the red transfer sample during the transfer test. Two discrimination ratios were determined for each subject in group UDO, one by computing the ratio of red-associate sample responses to total sample

responses over the final 4 sessions of training prior to the transfer session, and a second by computing the ratio of red transfer sample responses to total transfer sample responses during the first transfer session. However, the correlation between these two ratios was in fact negative, -.29, and did not differ significantly from zero in a *t*-test. Therefore, the transfer effect in group UDO cannot be explained in terms of transfer of differential rates of sample responding.

Thus, results of the transfer test indicate that pigeons formed expectancies of the nonhedonic differential outcomes. Group UDO showed a reliable transfer effect whereas group NDO demonstrated no evidence of transfer, and the transfer effect in group UDO could not be attributed to control by differential rates of sample responding. These findings indicate that expectancies of unidimensionally-different red and green outcomes can subsequently mediate performance in a novel DMTS task that presents those nonhedonic events as transfer samples. Specifically for group UDO, presentation of a particular outcome, red or green, as a transfer sample, tended to control choice of the specific shape test stimulus that, during training, had resulted in that particular event as the outcome. Presumably, such control was mediated by expectancies of the outcomes that corresponded to the transfer samples themselves. This process tended to facilitate accurate responding in the positive transfer condition, and suppress accurate responding in the negative transfer condition. By comparison for group NDO, presentation of a particular outcome, red or green, as a transfer sample, tended to control choice of both shape test stimuli because, during training, both events were equally likely as the outcome following correct choice of each shape test stimulus. Consequently, during the transfer session, control of choice responding could not be mediated by outcome

expectancies. Thus, neither facilitation of accurate responding in the positive transfer condition, nor suppression of accurate responding in the negative transfer condition, could occur.

Overall, results of the present experiment provide support for the claim that pigeons can form discriminable and memorable expectancies of unidimensionally-different nonhedonic outcomes. Nonhedonic DOEs were observed in acquisition and transfer testing, and a trend in this direction was observed during extended-delay testing. Importantly, such effects could not be attributed to behavioral processes based on differential sample responding. Evidently, expectancies of red and green outcomes in the present experiment appeared to provide a cue that was more discriminable, and slightly more memorable, than sensory features of circle and triangle shape stimuli alone. Additionally, such expectancies mediated transfer to a novel procedure in which those outcomes were presented as transfer samples.

Furthermore, these data discourage the view that the DOEs in Experiment 2 were produced by hedonic differences in the red and no-red outcome in group MDO, that resulted from differences in their effectiveness as secondary reinforcers. In the present experiment, there is no *a priori* reason to expect that one color should be a more effective secondary reinforcer than (and hence, hedonically preferable to) the other color. Therefore, the sample associates of the 2 outcomes should not have developed differences on the hedonic dimension. This conclusion is supported by analysis of differential sample responding, which did not differ between the 2 groups. Additional support comes from examination of accuracy on the 2 trial types in group UDO, which showed lower accuracy on trials in which the red-associated sample was presented than

on trials in which the green associated sample was presented, respectively, 89.1% and 93.4% in the final session of 0-s DMTS acquisition. Again, if accuracy is an indication of the hedonic value of an outcome, then there is no evidence to show that the red and green events differed along the hedonic dimension.

Therefore, the transfer effect in group UDO indicates that expectancies of the unidimensionally-different nonhedonic outcomes likely mediated performance. And the only means by which this could have happened is if subjects had learned, during acquisition, to expect the red outcome whenever the red-associated sample was presented, and to expect the green outcome whenever the green-associated sample was presented.

To summarize, failure to detect nonhedonic DOEs in Experiment 1 may not be attributable to use of unidimensionally-different outcomes. Rather, failure may have been due to use of a relatively easy line-orientation (rather than a difficult shape) discrimination, presentation of the color outcome on only the center key (rather than on all three keys), comparison of positive to neutral (rather than to negative) transfer conditions, use of a complex (rather than a simple) transfer task, or to any combination of these factors. Still, it cannot be entirely ruled out that previous use of expectancies of multidimensionally-different outcomes in Experiment 2 might have potentiated use of expectancies of unidimensionally-differential outcomes in the present group UDO. In other words, having previously learned to expect the red and no-red outcomes might have enabled pigeons' present ability to expect red and green outcomes. Regardless, the present results demonstrate that pigeons can develop and use expectancies of unidimensionally-different nonhedonic outcomes.

General Discussion

For years, investigators have been concerned with processes that mediate between an external controlling stimulus and an instrumental response (e.g., Tinklepaugh, 1928; Trapold & Winokur, 1967). Most early theorists regarded this mediational process as an elicited behavioral state, and hence believed that the resulting stimulus feedback came to control the instrumental response (Hull, 1930, 1931; Spence, 1956). More recently, authors conceptualized the mediation in terms of an internal emotional or drive state that motivated instrumental responding (Rescorla & Solomon, 1967). It was not until the early 1970s that writers began to characterize the mediation in terms of a central or cognitive expectancy state (Trapold, 1970; Trapold & Overmier, 1972). Nevertheless, mediation by behavioral states, motivational states, and expectancy states, are not mutually exclusive mechanisms. Indeed, it is possible that all three processes play a mediating role in many instances of instrumental performance. Thus, the problem for the experimental psychologist who is interested specifically in expectancies is to design a procedure that reveals the expectancy process, while at the same time controls or eliminates confounding behavioral and motivational processes.

On expectancy theory, instrumental responding is thought to be controlled, at least in part, by an expectancy of a forthcoming event (e.g., primary or secondary reinforcement), an expectancy that can be activated by explicit discriminative stimuli in the instrumental conditioning situation. An expectancy of a reinforcer is thought to comprise a central representation (e.g., Roitblat, 1982) of the reinforcer, which is believed to contain a complex of stimulus information about the reinforcer: For instance, its color, texture, sound, smell, taste, spatial location, and so forth. The DMTS task with

nonhedonic differential outcomes provides an excellent tool to investigate the precise nature and content of expectancies in pigeons. It is these considerations that motivated the present series of experiments. Specifically: (1) Can evidence of expectancies be obtained, independent of the role of behavioral or motivational mechanisms? (2) What *kinds* of information about an outcome may be contained in its central representation? (3) When is this information expressed in behavior? The reader should note that these questions relate very closely to the 3 basic questions that have been asked of other learning phenomena: Respectively: (1) The *conditions* of learning, (2) The *content* of learning, and (3) The *performance rules* by which learning is expressed in behavior (Rescorla, 1988).

With regards to the "conditions" question, Experiments 2 and 3 confirmed that the role of expectancies can indeed be separated from the influence of behavioral and motivational mechanisms. Birds for which differential outcome expectancies were distinguished neither by behavioral nor motivational characteristics, but rather only by stimulus characteristics (group MDO in Experiment 2 and group UDO in Experiment 3), demonstrated stronger learning, working memory, and mediated-transfer performance, compared to their counterparts (group NDO) for which outcome expectancies were indistinguishable on behavioral, motivational, and sensory characteristics.

With regards to the "content" question, evidence of nonhedonic DOEs suggests that a representation of an outcome can contain fairly specific information about the stimulus characteristics of that outcome. Reconsider, for example, differences in performance between groups MDO and NDO in Experiment 2. If one accepts the view that the two outcomes, red (followed by reinforcement) and no red (followed by

reinforcement), differed solely on the basis of the presence or absence of a nominally nonhedonic event that preceded food or no food, then, for birds in group MDO, expectancies of the multidimensionally-different outcomes that were activated by the samples must have contained information about the presence and absence of the red event that preceded reinforcement (e.g., a "red-reinforcement" expectancy, and a "no red-reinforcement" expectancy).

In addition, reconsider differences in performance between groups UDO and NDO in Experiment 3. Here, the red and green outcomes differed unidimensionally, thereby suggesting that for birds in group UDO, expectancies must have contained information about the color of the event that preceded reinforcement (e.g., a "red-reinforcement" expectancy, and a "green-reinforcement" expectancy). Other information about the specific aspects of an outcome that can be contained in an expectancy (e.g., specific auditory, gustatory, or olfactory features of the outcome) is an area in which procedures of the present series of experiments could prove very useful

With regards to the "performance rule" question, an issue raised in this study that deserves further investigation is the elusiveness of the nonhedonic DOE on working memory, at least when unidimensionally-different outcomes (e.g., red and green) are employed. Recall that equivalent retention was observed in groups CDO and NDO in Experiment 1, and in groups UDO and NDO in Experiment 3. In addition, group MDO showed stronger retention than group NDO at the 2-s delay but not the 6-s delay in Experiment 2. Moreover, these weak or absent DOEs in retention were in marked contrast to the reliable DOEs with nonhedonic outcomes that were observed on other indicants (i.e., acquisition and transfer in Experiments 2 and 3).

It is possible that uninteresting procedural factors were responsible for weak or absent nonhedonic DOEs in retention. Specifically, in DOE studies that have used hedonic outcomes, extended-delay testing is typically much more prolonged and animals experience a much larger proportion of extended-delay trials, compared to the present series of experiments. For instance, Peterson et al. (1980) gave their birds at least 10 consecutive test sessions in which an extended delay was presented on all trials. Edwards et al.'s (1982) extended-delay test comprised at least 20 consecutive test sessions in which the ratio of baseline (0-s delay) trials to extended-delay trials was 1:2. Urcuioli's (1990) procedure involved 15 consecutive test sessions with a 1:3 ratio of baseline to extended-delay trials. By comparison, each extended-delay test in the present study comprised only 4 consecutive test sessions, with a 3:1 ratio of baseline to extended-delay trials. Although a strong hedonic DOE in retention was observed in Experiment 1 using these procedures, perhaps a nonhedonic DOE in retention would emerge only under conditions of prolonged extended-delay testing, in which a larger proportion of extended-delay trials are presented.

Alternatively, it is possible that expectancies provided by nonhedonic outcomes are difficult for pigeons to retain in working memory. On this account, the additional cues provided by expectancies of red, no-red, and green events, can facilitate 0-s DMTS acquisition and provide effective mediators in a 0-s delay transfer test. However, after they are activated, those expectancies dissipate very quickly. Therefore, nonhedonic outcome expectancies may be unavailable to facilitate retention performance, especially at longer delays. Perhaps a strong hedonic component is necessary for an expectancy to be retained in working memory.

The "affective extension" of the "sometimes-opponent process" (AESOP) theory of Wagner and Brandon (1989) provides a ready explanation for strong nonhedonic DOEs in acquisition and transfer, but not in retention performance. This model also accounts for strong hedonic DOEs throughout acquisition, transfer, and retention. In the AESOP model, presentation of a sample activates affective and sensory elements of the outcome representation from an inactive (I) state to an intermediate (A2) state of activation. An A2 state of activation corresponds to a memory of the event that is represented. Next, upon sample termination, A2 elements of the outcome representation gradually return (decay) to the I state, with sensory elements tending to decay more rapidly than affective elements.

Because the red, no-red, and green outcomes are nonhedonic events, A2 representations of these outcomes should consist primarily of quick-to-decay sensory elements. By comparison, because the food and no-food outcomes are hedonic events, A2 representations of these outcomes should consist of both quick-to-decay sensory elements, and slow-to-decay affective elements. Thus, both nonhedonic and hedonic A2 representations should have active elements available to mediate performance at short delays (e.g., 0-s DMTS acquisition, 0-s delay transfer). However, only the hedonic A2 representation would likely have active (affective) elements available to mediate performance at longer delays (e.g., extended-delay testing).

In summary, the present study indicates that the role of cognitive expectancies in instrumental performance can be examined in isolation from the influences of alternate mediational processes. Additionally, information about the presence and absence of an event, and information about the color of an event, can be represented in the expectancy

of an outcome, although indicants of such information are more evident in acquisition and transfer performance, and less evident in extended-delay performance.

Table 1. *Conditional discrimination* with *differential outcomes and nondifferential outcomes.*

Group	Stimulus	Choice Responsé	Outcome
Differential Outcomes (DO)	S1	R1	O1
		R2	Nothing
	S2	R1	Nothing
		R2	O2
Nondifferential Outcomes (NDO)	S1	R1	O1 or O2
		R2	Nothing
	S2	R1	Nothing
		R2	O1 or O2

Note. S1 = stimulus 1 (e.g., green), S2 = stimulus 2 (e.g., red), R1 = response 1 (e.g., choice of horizontal-line orientation), R2 = response 2 (e.g., choice of vertical-line orientation), O1 = outcome 1 (e.g., food), O2 = outcome 2 (e.g., water).

Table 2. *Delayed matching-to-sample task in Experiment 1: Hedonic differential outcomes, color differential outcomes, and nondifferential outcomes.*

Group	Stimulus	Choice Response	Color outcome	Hedonic Outcome
Hedonic Differential Outcomes (HDO)	H	H	G or R	F
		V	Nothing	Nothing
	V	H	Nothing	Nothing
		V	G or R	NF
Color Differential Outcomes (CDO)	H	H	G	F or NF
		V	Nothing	Nothing
	V	H	Nothing	Nothing
		V	R	F or NF
Nondifferential Outcomes (NDO)	H	H	G or R	F or NF
		V	Nothing	Nothing
	V	H	Nothing	Nothing
		V	G or R	F or NF

Note. H = horizontal line orientation, V = vertical line orientation, G = green, R = red, F = illuminated food, NF = illuminated no food. For clarity, counterbalancing of associations between sample-response sequences and color outcomes within group CDO, and between sample-response sequences and hedonic outcomes within group HDO, has not been illustrated.

Table 3. *Delayed matching-to-sample task in Experiment 2: Multidimensional differential outcomes and nondifferential outcomes.*

Group	Stimulus	Choice Response	Color outcome	Hedonic Outcome
Multidimensional Differential Outcomes (MDO)	C	C	R	F or NF
		T	Nothing	Nothing
	T	C	Nothing	Nothing
		T	NR	F or NF
Nondifferential Outcomes (NDO)	C	C	R or NR	F or NF
		T	Nothing	Nothing
	T	C	Nothing	Nothing
		T	R or NR	F or NF

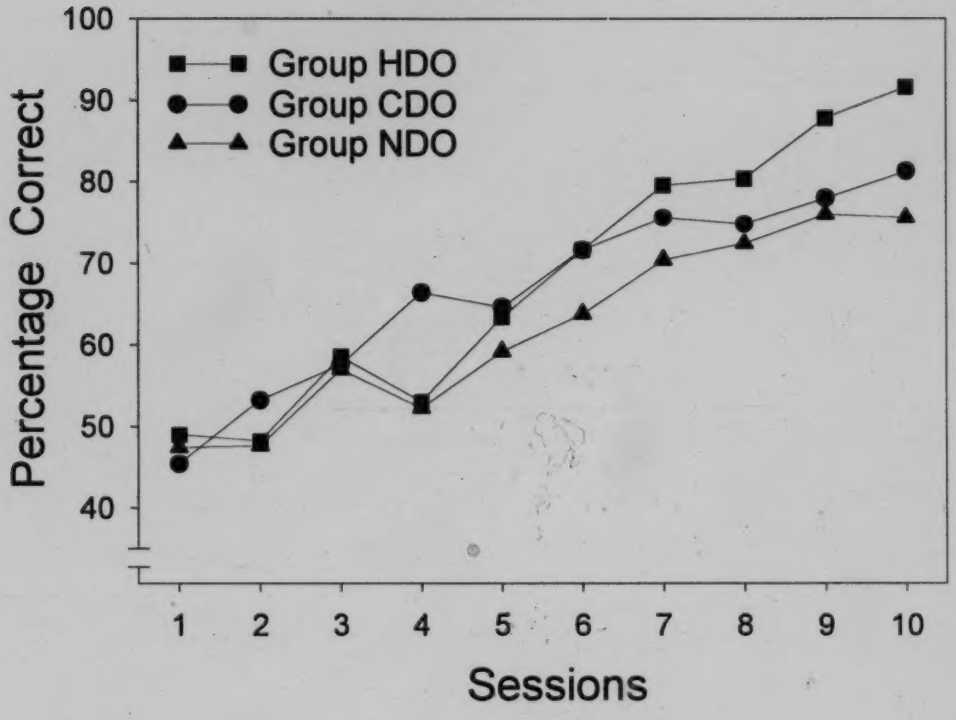
Note. C = circle shape, T = triangle shape, R = red, NR = no red, F = illuminated food, NF = illuminated no food. For clarity, counterbalancing of associations between sample-response sequences and outcomes within group MDO has not been illustrated.

Table 4. *Delayed matching-to-sample task in Experiment 3: Unidimensional differential outcomes and nondifferential outcomes.*

Group	Stimulus	Choice Response	Color outcome	Hedonic Outcome
Unidimensional Differential Outcomes (UDO)	C	C	R	F or NF
		T	Nothing	Nothing
	T	C	Nothing	Nothing
		T	G	F or NF
Nondifferential Outcomes (NDO)	C	C	R or G	F or NF
		T	Nothing	Nothing
	T	C	Nothing	Nothing
		T	R or G	F or NF

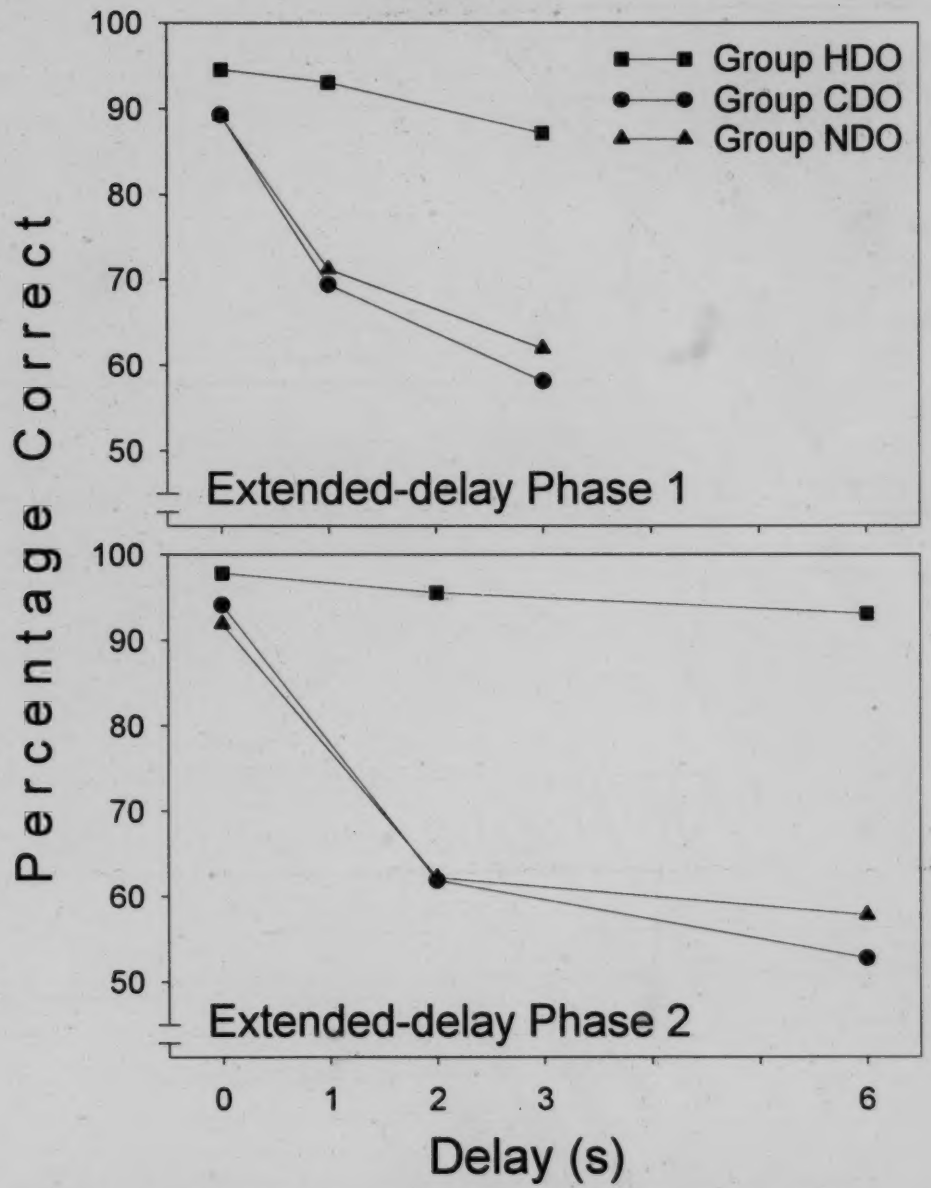
Note. C = circle shape, T = triangle shape, R = red, G = green, F = illuminated food, NF = illuminated no food. For clarity, counterbalancing of associations between sample-response sequences and outcomes within group UDO has not been illustrated.

Figure 1



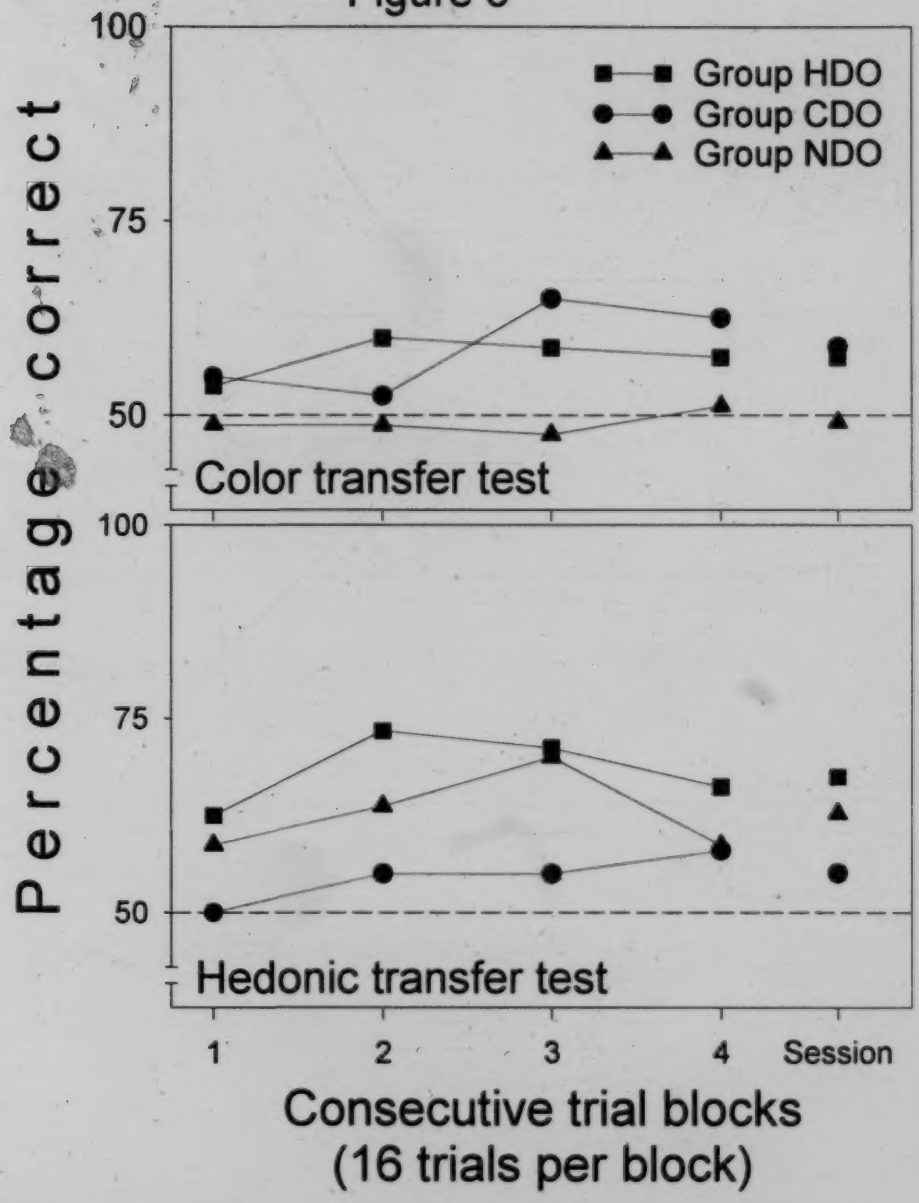
Experiment 1: 0-s DMTS Acquisition. Accuracy (mean percentage of correct choices) in groups hedonic differential outcomes (HDO), color differential outcomes (CDO), and nondifferential outcomes (NDO), over the first 10 sessions of acquisition in Experiment 1, the only sessions from which there were data for all subjects.

Figure 2



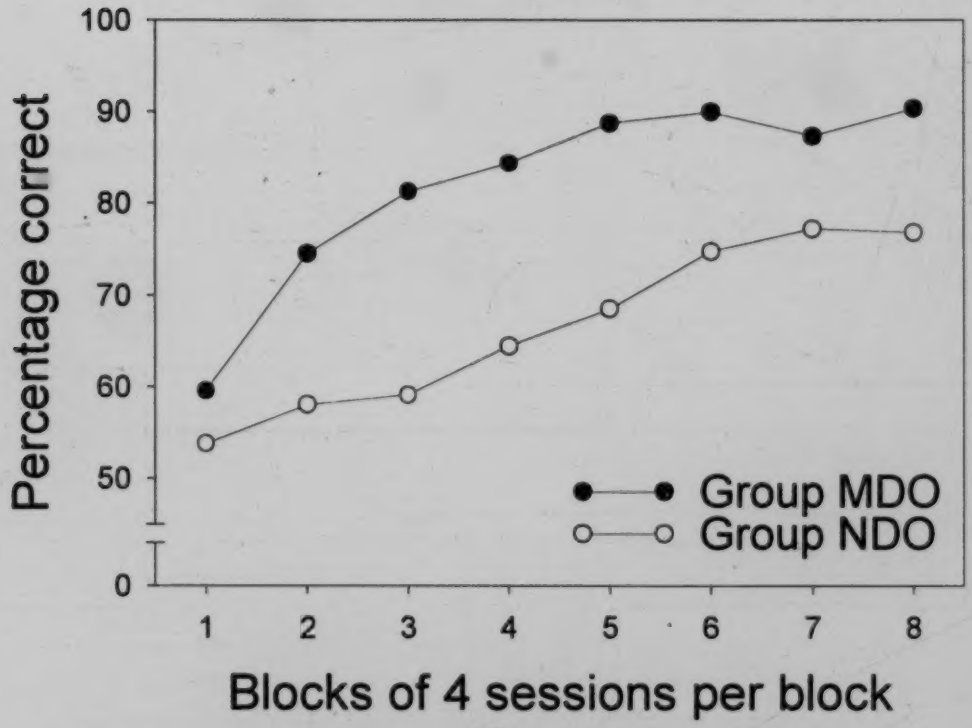
Experiment 1: Extended-delay Testing. Accuracy (mean percentage of correct choices) in groups hedonic differential outcomes (HDO), color differential outcomes (CDO), and nondifferential outcomes (NDO), as a function of delay in the first phase (upper panel) and second phase (lower panel) of extended-delay testing in Experiment 1. Data are collapsed over replications within each phase.

Figure 3



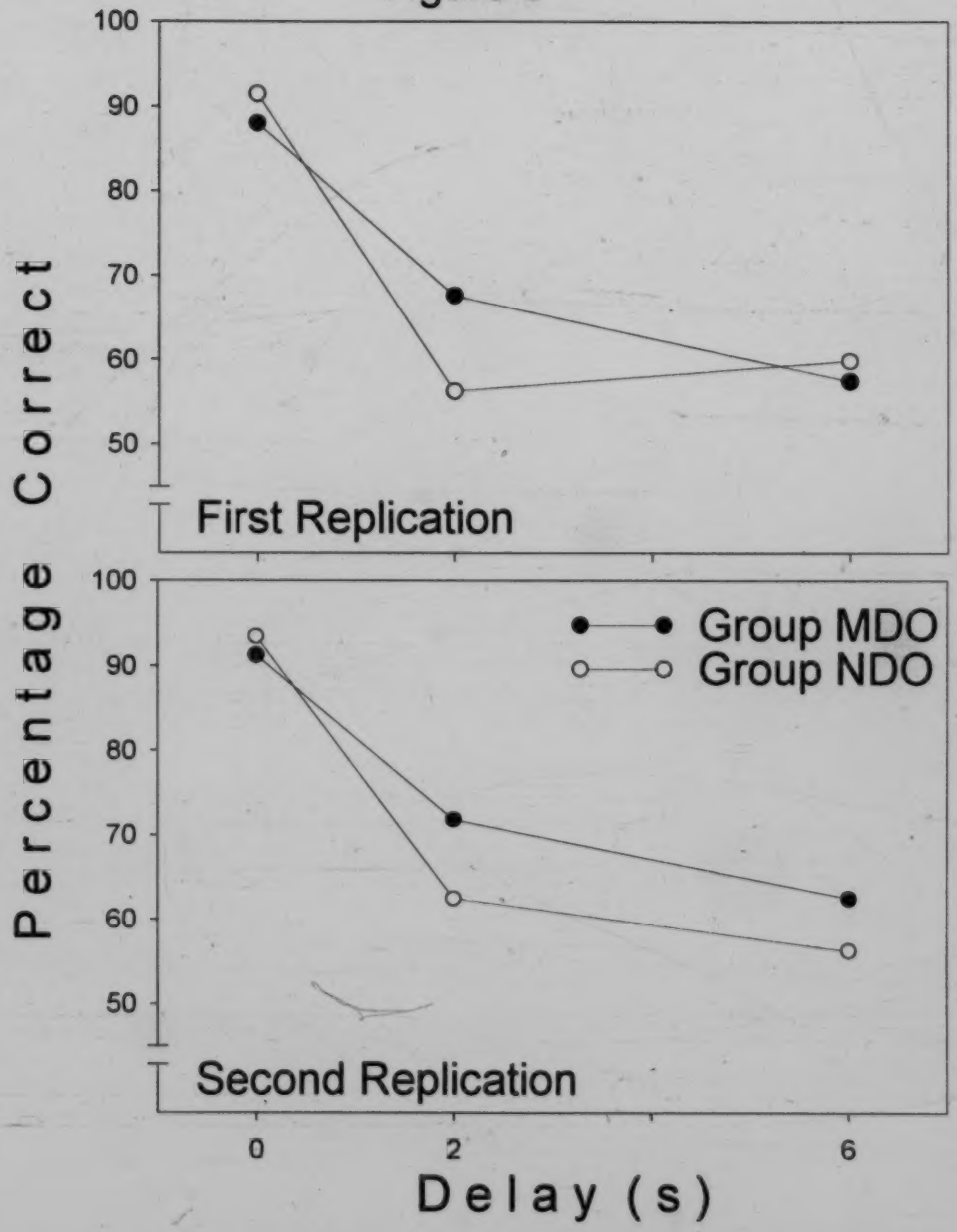
Experiment 1: Transfer Testing. Accuracy (mean percentage of correct choices) in groups hedonic differential outcomes (HDO), color differential outcomes (CDO), and nondifferential outcomes (NDO), as a function of consecutive trial blocks, and the mean of all trials blocks (session), in the color test session (upper panel) and the hedonic test session (lower panel) of transfer testing in Experiment 1.

Figure 4



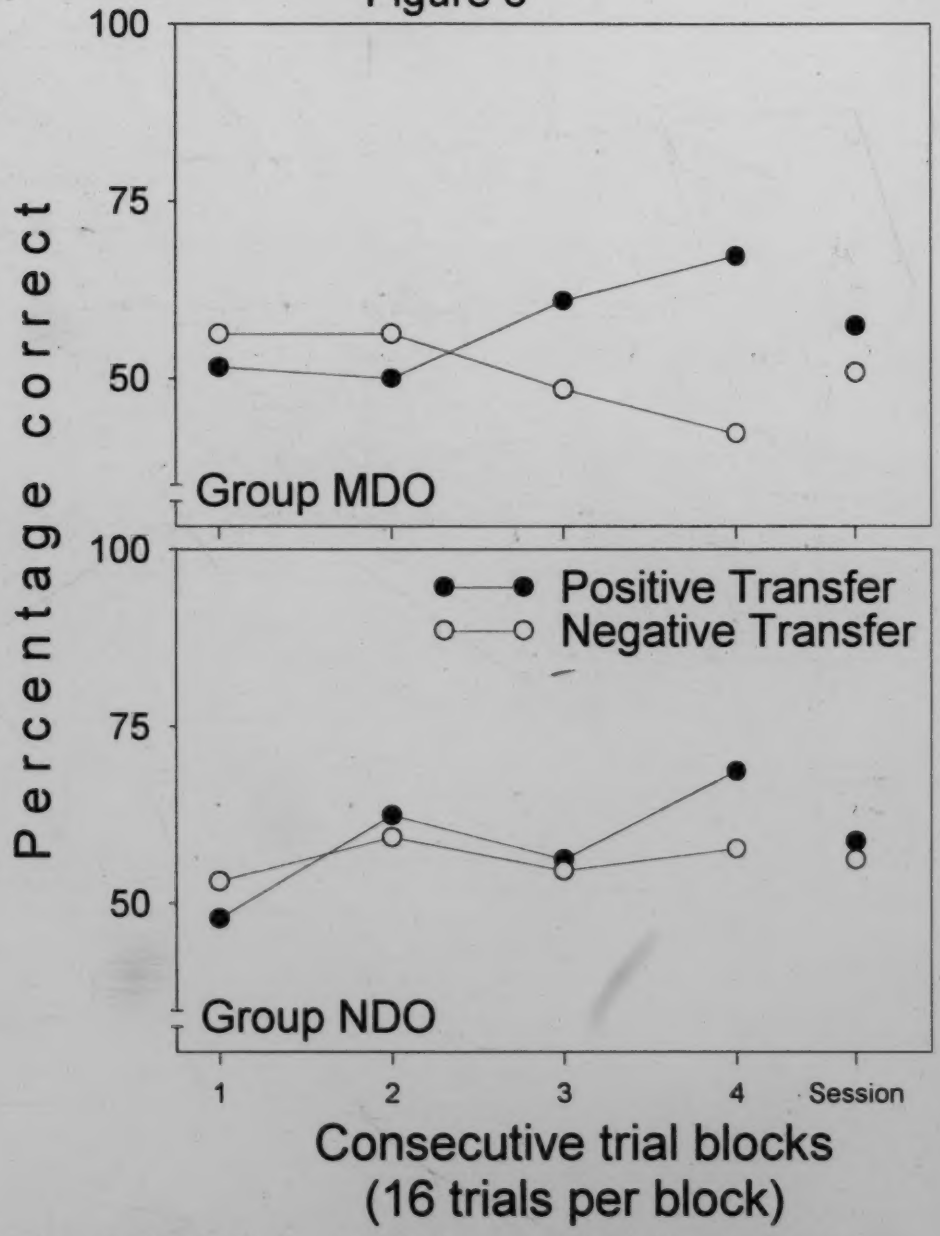
Experiment 2: 0-s DMTS Acquisition. Accuracy (mean percentage of correct choices) in groups multidimensional differential outcomes (MDO) and nondifferential outcomes (NDO), over the first 8 blocks of acquisition in Experiment 2, the only blocks from which there were data for all subjects.

Figure 5



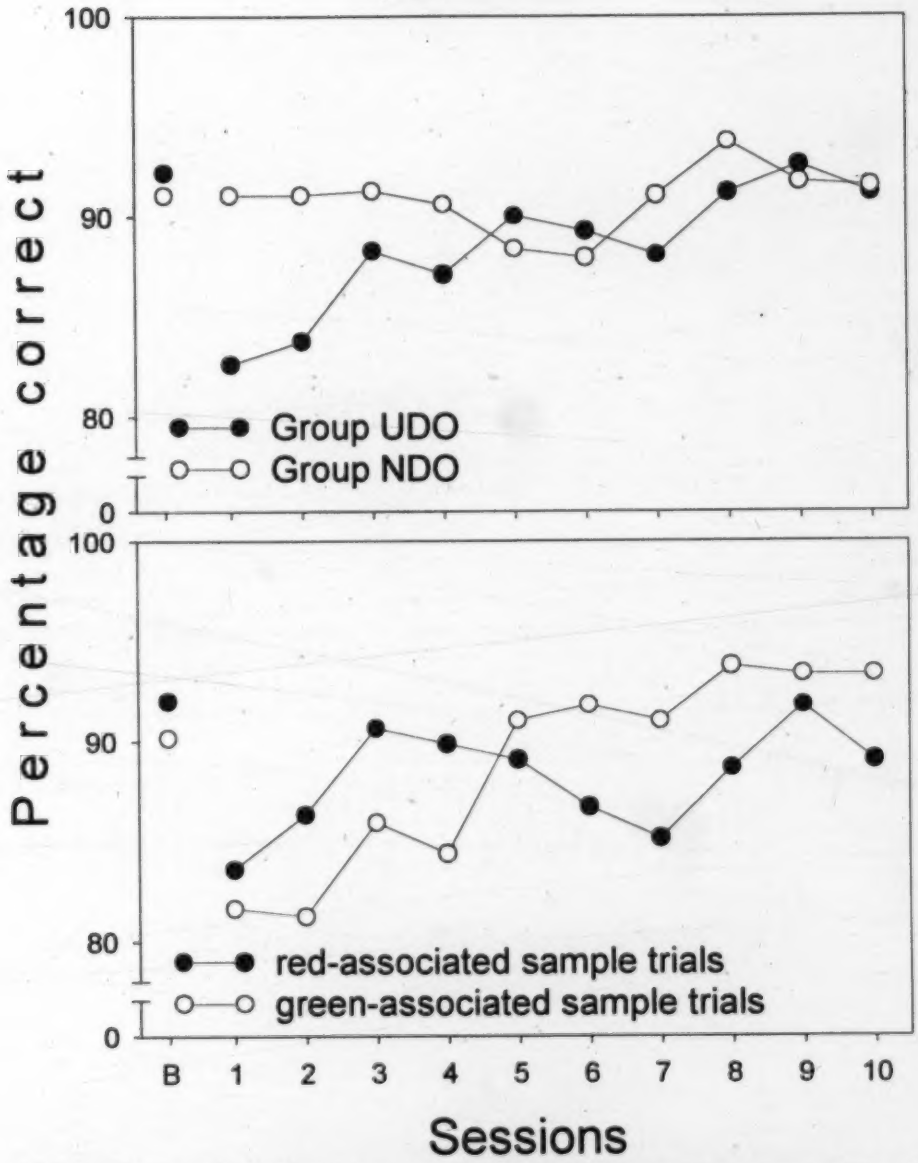
Experiment 2: Extended-delay Testing. Accuracy (mean percentage of correct choices) in groups multidimensional differential outcomes (MDO) and nondifferential outcomes (NDO), as a function of delay in the first replication (upper panel) and second replication (lower panel) of extended-delay testing in Experiment 2.

Figure 6



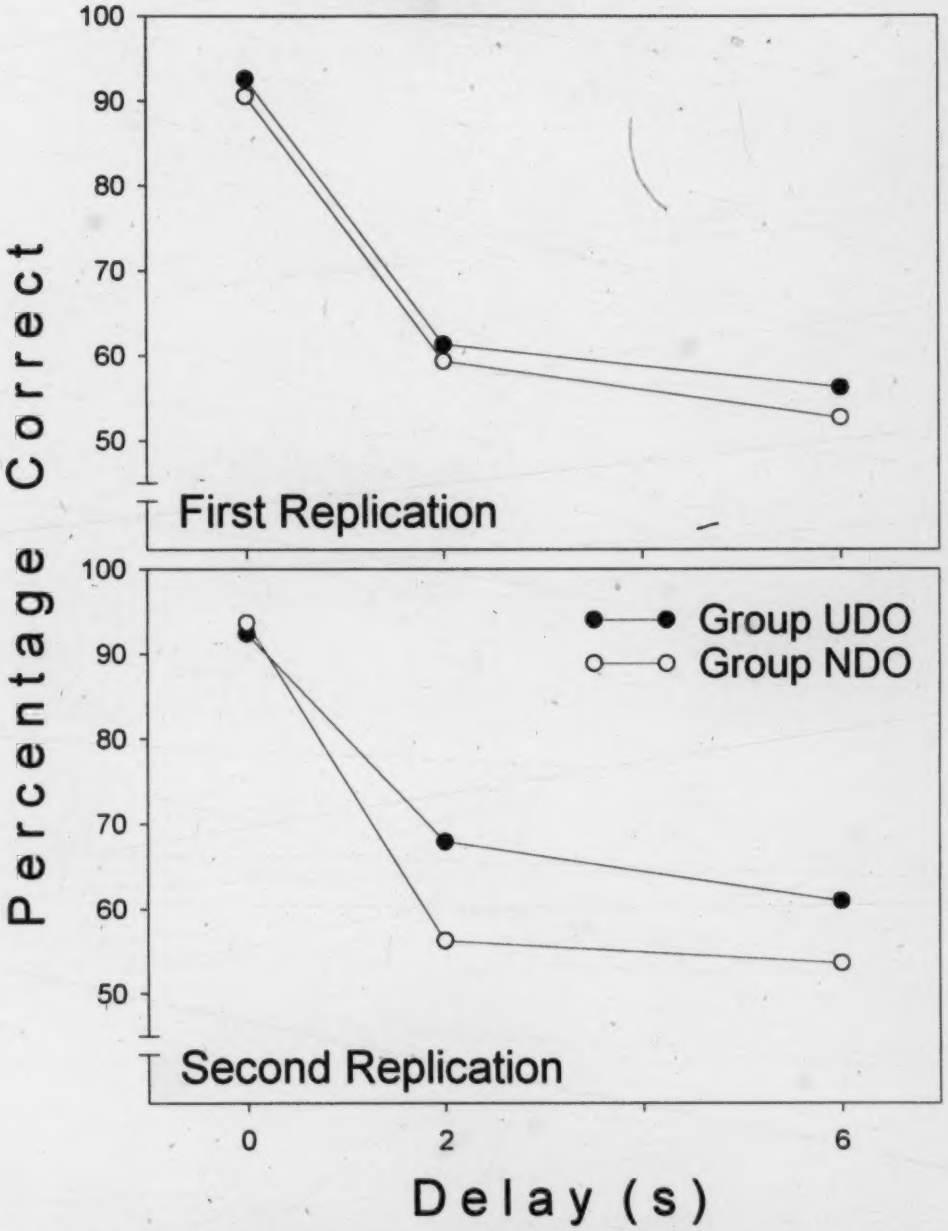
Experiment 2: Transfer Testing. Accuracy (mean percentage of correct choices) in positive and negative transfer conditions of group multidimensional differential outcomes (MDO, upper panel) and group nondifferential outcomes (NDO, lower panel), as a function of successive trial blocks, and the mean of all trials blocks (session), in the single session of transfer testing in Experiment 2.

Figure 7



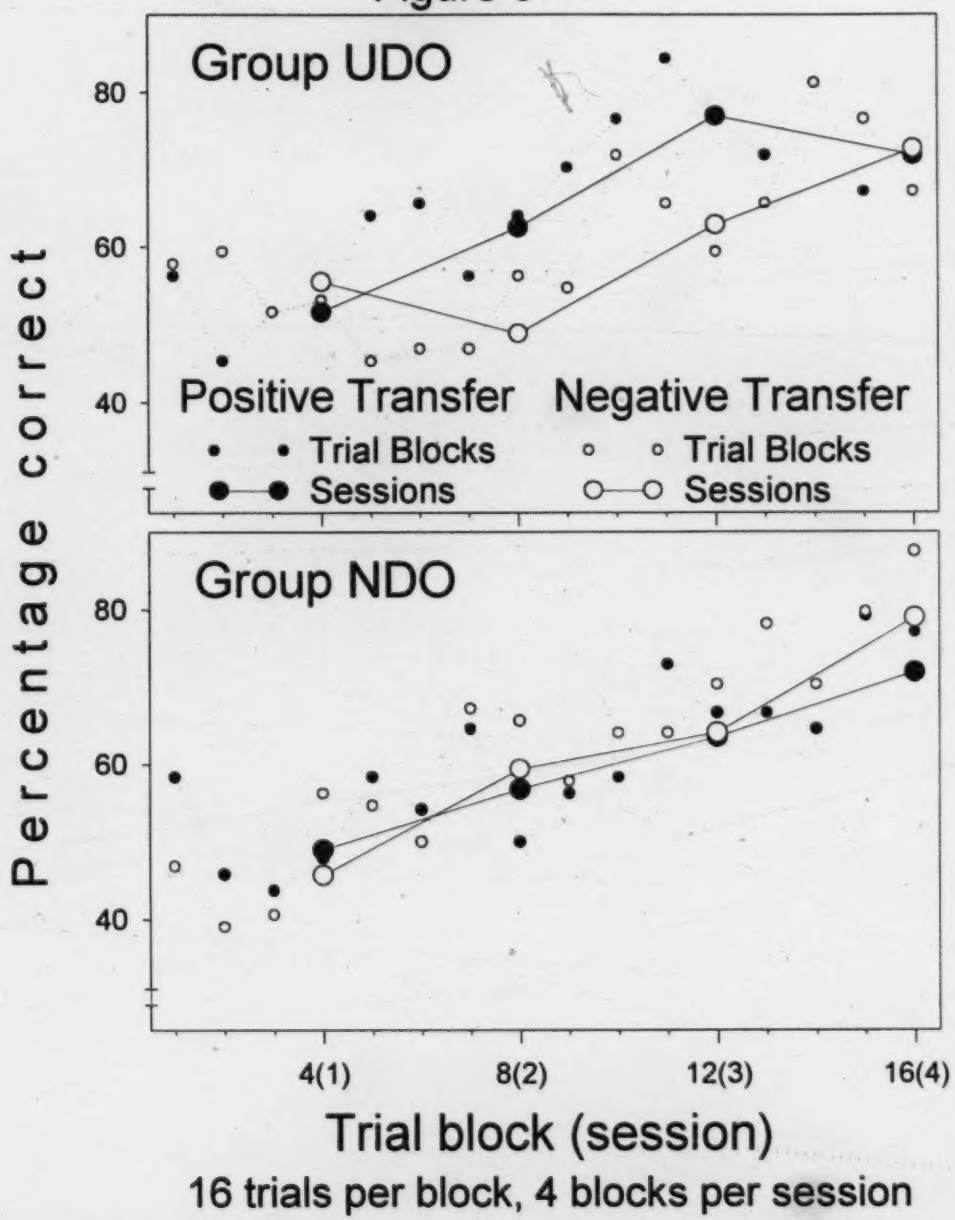
Experiment 3: 0-s DMTS Acquisition. Accuracy (mean percentage of correct choices) in groups unidimensional differential outcomes (UDO) and nondifferential outcomes (NDO), over the final 4 sessions of 0-s DMTS baseline training with multidimensionally-different red and no-red outcomes (just prior to transfer testing in Experiment 2), and over the 10 sessions of acquisition with unidimensionally-different red and green outcomes in Experiment 3 (upper panel). Accuracy is separated with respect to red-associated and no-red associated sample types in group UDO (lower panel).

Figure 8



Experiment 3: Extended-delay Testing. Accuracy (mean percentage of correct choices) in groups unidimensional differential outcomes (UDO) and nondifferential outcomes (NDO), as a function of delay in the first replication (upper panel) and second replication (lower panel) of extended-delay testing in Experiment 3.

Figure 9



Experiment 3: Transfer Testing. Accuracy (mean percentage of correct choices) in positive and negative transfer conditions of groups unidimensional differential outcomes (UDO, upper panel) and nondifferential outcomes (NDO, lower panel), as a function of trial block (small symbols) and session (large symbols) in the 4 sessions of transfer testing in Experiment 3.

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